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ABSTRACT

This technical specialty course is one of thirty-five courses designed for use by two-year postsecondary institutions in five nuclear technician curriculum areas: (1) radiation protection technician, (2) nuclear instrumentation and control technician, (3) nuclear materials processing technician, (4) nuclear quality-assurance/quality-control technician, and (5) nuclear reactor (plant) operator trainee. This course, Mechanical Inspection, contains eight modules: Pump Inspection: Pump Functional Testing; Valve Inspection: Piping Inspection: Surface Cleaning Inspection: Protective Coating Inspection: Pressure Vessel Inspection; and Rotating Equipment Inspection. Each module follows a typical format including the following sections: introduction, module prerequisites, objectives, subject matter, exercises, materials, procedures, data tables, reference materials, and tests. (A master index and suggested program planning guides are also available--see CE 026 856 and CE 026 639-643.) (LRA)

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Nuclear Technology Series

COURSE 30

MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH
AND DEVELOPMENT, INC.

4800 LAKEWOOD DRIVE
WACO, TEXAS 76710

AUG 1980

U.S. DEPARTMENT OF HEALTH,
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PREFACE

ABOUT NUCLEAR TECHNOLOGY MODULES

The modules – developed for use in two-year postsecondary technical institutions to prepare technicians for employment – are useful in industry for updating employees in company-sponsored training, and as laboratory texts in engineering schools. The principles, techniques and skills taught in the modules, based on tasks that nuclear technicians perform, were obtained from a nationwide advisory committee of employers of nuclear technicians. Each module was written by a working technical expert/experienced writer team and tested with students.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.
Module Prerequisites, which identify the material a student should be familiar with before studying the module.
Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify and define, rather than words with many interpretations, such as know, understand, learn and appreciate.
Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.
Exercises, which provide practical problems to which the student can apply this new knowledge.
Materials, which identify the equipment required to complete the laboratory procedure.
Procedures, which is the experiment section, or "hands-on" portion of the module (including step-by-step instruction) designed to reinforce student learning.
Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.
Reference Materials, which are included as suggestions for supplementary reading/viewing for the student.
Test, which measures the student's achievement of the prestated objectives.

A helpful Index has been added at the end of each course.

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The Nuclear Technology Series consists of five curricula:

Nuclear Reactor (Plant) Operator Trainee.
Radiation Protection Technician.
Nuclear Materials Processing Technician.
Nuclear Quality-Assurance/Quality-Control Technician.
Nuclear Instrumentation and Control Technician.

The completed Nuclear Technology Series consists of the following 35 technical specialty courses:

Radiation Physics.
Radiation Protection I.
Principles of Process Instrumentation.
Heat Transfer and Fluid Flow.
Introduction to Nuclear Systems.
Instrumentation and Control of Reactors and Plant Systems.
Reactor Operations.
Reactor Safety.
Reactor Auxiliary Systems.
Power Plant Systems.
Radiation Detection and Measurement.
Reactor Physics.
Power Plant Chemistry.
Introduction to Quality Assurance/ Quality Control.
Metallurgy and Metals Properties.
Mechanical Component Characteristics and Specifications.
Radiation Protection II.
Radiological Emergencies.
Radiation Shielding.
Radiation Monitoring Techniques (Radiochemical).
Radioactive Materials Disposal and Management.
Advanced Radionuclide Analysis.
Nuclear Chemical Processes.
Nuclear Systems and Safety.
Radioactive Material Handling Techniques.
Nondestructive Examination (NDE) Techniques I.
Metrology.
Welding Inspection.
Civil/Structural Inspection.
Mechanical Inspection.
Quality-Assurance Practices.
Nondestructive Examination (NDE) Techniques II.
Control Systems I.
Control Systems II.
Power Plant Electrical Systems and Components.

Availability: Instructional modules are available individually or by courses from:

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Printed:

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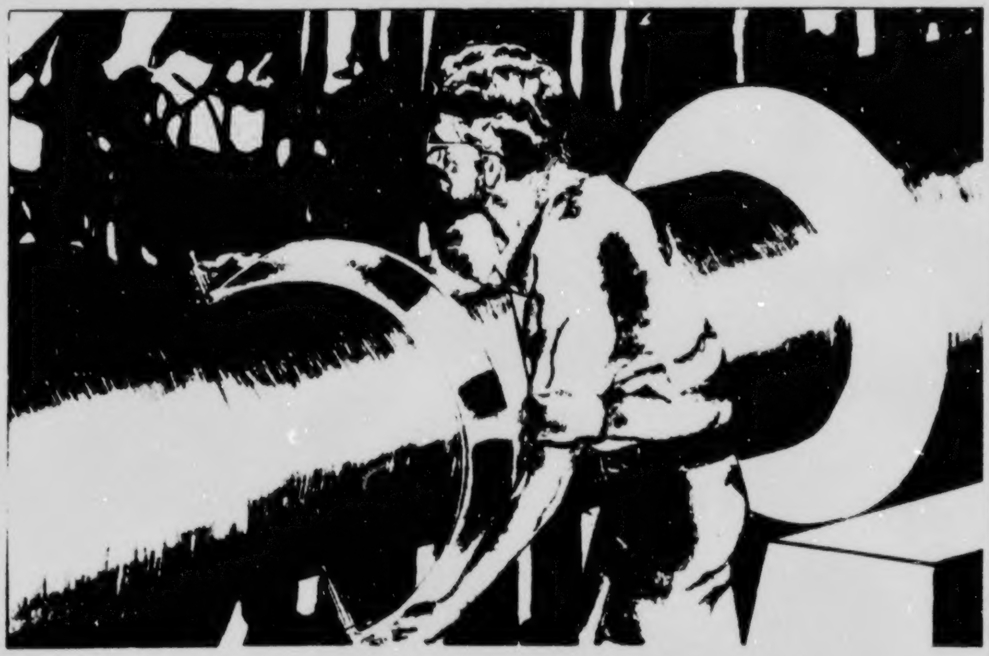
NUCLEAR TECHNOLOGY

MODULE 30-1

PUMP INSPECTION



COURSE 30 MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
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COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

MODULE 30-1	Pump Inspection
MODULE 30-2	Pump Functional Testing
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MODULE 30-6	Protective Coating Inspection
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MODULE 30-8	Rotating Equipment Inspection

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INTRODUCTION

The Nuclear QA/QC Technician typically performs inspection of pump installation activities in accordance with written procedures. These inspections consist of observing work practices, visually inspecting pumps and surroundings, and reviewing records. The objective of these inspections is to verify that the correct pump is properly installed in the right location. This module describes these inspection activities.

Prior to describing inspection activities, this module describes the types of pumps used in the nuclear power plant systems and the basic operating principles of each type. This fundamental description of technical features of pumps should assist the student/trainee in visualizing the application of inspection activities.

Inspection activities are described for the period of time from release of a pump from stores until the time of functionally testing the pump after installation. These inspections are divided into three phases consisting of preinstallation inspections, installation inspection, and preoperational integrity tests. It is noted that Module 30-2 of Course 30 describes preoperational functional testing of components.

MODULE PREREQUISITES

It is suggested that the student/trainee complete Course 15, Metallurgy and Metal Properties prior to beginning this course.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Describe the fundamental operating principles associated with centrifugal, jet, and displacement pumps.
2. Define:
   a. static suction lift
   b. static suction head
   c. discharge head
   d. total static head
3. Describe how dynamic heads differ from static heads with respect to suction, discharge, and pump heads.
4. State the purpose of preinstallation inspection.
5. Describe the preinstallation inspections associated with identification, processes and procedures, pump physical conditions, and site conditions.
6. State the purpose of installation inspections.
7. Describe the installation inspections associated with control of procedures and processes, nondestructive examinations, work in progress, and final installation.
8. Briefly describe how to conduct a shaft seal/leakage test.
9. Briefly describe how to conduct a hydrostatic test.

FUNDAMENTAL PUMP DESIGNS

Classification of Pumps

Pumps may be classified on the basis of their applications, the materials from which they are constructed, or the fluids which they handle. In all of these classifications, however, is a more basic classification which is based on the principles of operation of the pumps. Every pump imparts energy to the fluid it handles and the principles by which this energy is added to the fluid provides a basis of pump classification which has universal meaning regardless of any additional classification. These principles provide for classifications of pumps into two categories: dynamic and displacement as illustrated in Figure 30-1-1.

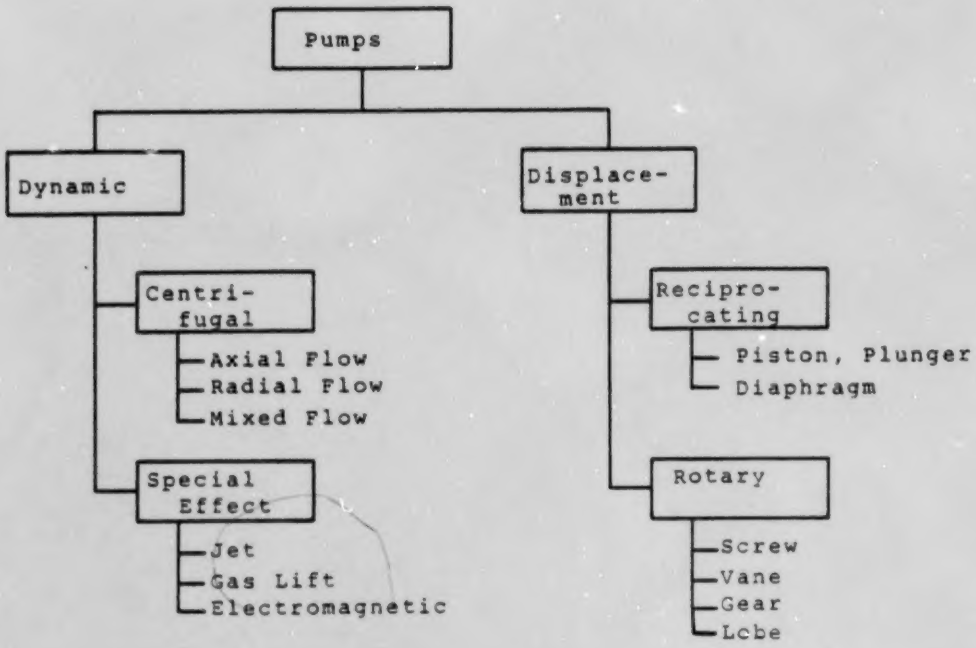

Pumps
Dynamic
Displacement
Centrifugal
Axial Flow
Radial Flow
Mixed Flow
Special Effect
Jet
Gas Lift
Electromagnetic
Reciprocating
Piston, Plunger
Diaphragm
Rotary
Screw
Vane
Gear
Lobe

Figure 30-1-1. Classification of Pumps

Dynamic pumps continuously add energy to increase fluid velocity within the pump such that subsequent velocity reduction within or beyond the pump produces a pressure increase. Dynamic pumps are comprised of centrifugal pumps and special effect pumps such as jet pumps and electromagnetic pumps.

Displacement pumps periodically add energy by physically moving an enclosed volume of fluid which results in a pressure increase up to a value required to move that volume into the discharge line. Displacement pumps are comprised of reciprocating and rotary pumps.

Water Height Versus Pressure

A direct correlation exists between the height of a column of water and the pressure at the base of the column due to the force of gravity. At the standard temperature of 68°F, this correlation is 100 pounds per square inch (psi) for each 231 feet of water as illustrated in Figure 30-1-2. It is noted that the relationship is valid whether measuring the force of an existing column of water or calculating the height that a column of water would achieve if a known pressure were applied at the base of the column.

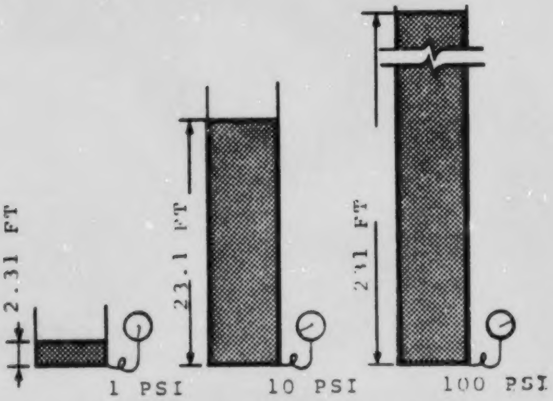


Figure 30-1-2. Effect of water height on pressure

Suction Lift and Suction Head

Design of a pump permits its use at a placement above or below the level of fluid supply. Pumps which operate at a placement above the level of fluid supply must be capable of lifting the fluid to the axis of the pump. This distance in feet is termed static suction lift and is illustrated in Figure 30-1-3

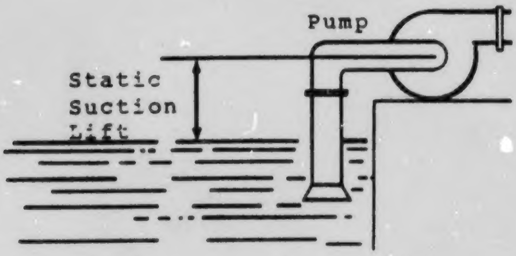


Figure 30-1-3. Static suction lift.

Pumps which operate at a placement below the level of fluid supply have a pressure at their suction which is generated by the height of fluid above the axis of the pump. This height of fluid in feet is termed static suction head and is illustrated in Figure 30-1-4.

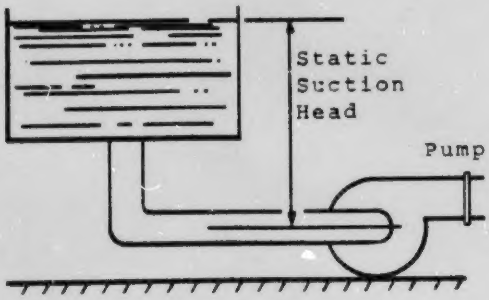


Figure 30-1-4. Static suction head.

When a pump is operating, the static suction lift and static suction head are not directly sensed by the pump. This is because the fluid is flowing at some velocity and because there are frictional losses in the line. An operating pump located above the supply of fluid must be capable of a total dynamic suction lift equal to the static suction lift plus the velocity head plus the frictional losses. An operating pump located below the supply of fluid must be capable of operating at a total dynamic suction head of the static suction head minus the velocity head minus the frictional losses.

The velocity head is the equivalent height in feet that the fluid would have to fall to equal the fluid velocity produced by the action of the pump. Velocity head is expressed by the equation:

$$h=\frac{v^2}{2g} \qquad 30\text{-}1\text{-}1$$

where:

h = velocity head in feet

v = velocity of fluid flow in feet per second

g = gravitational acceleration (32.2 ft/sec^2)

The maximum dynamic suction lift or the minimum suction head which is required for proper pump operation is termed minimum net positive suction head (MNPSH). When the dynamic absolute pressure at the pump suction is less than MNPSH, vapor cavities occur which is termed cavitation. At any absolute pressure greater than MNPSH, the pump will operate without cavitation. The exact value for MNPSH is dependent on the design of the pump, the type of fluid being pumped, and the temperature of the pumped fluid. MNPSH is described in more detail in Module 30-2 with regard to pump functional testing.

Discharge Head and Total Static Head

If a vertical column were added to the discharge side of a dynamic pump, the fluid would rise to a level designated as the discharge head. For displacement pumps, an equivalent measure of discharge head is in pounds per square inch. The discharge head is measured from the level of the pump and is comprised of a pressure head, velocity head, and elevation head.

The absolute difference between the discharge head and the suction head is the pump head or total head. The total head may be considered in terms of total static head or total dynamic head. Total static head takes into account the difference in fluid level from suction to discharge. Total dynamic head additionally takes into account velocities, fluid density, and frictional losses of a specific pump system. Discharge head and total static head are illustrated in Figures 30-1-5 and 30-1-6.

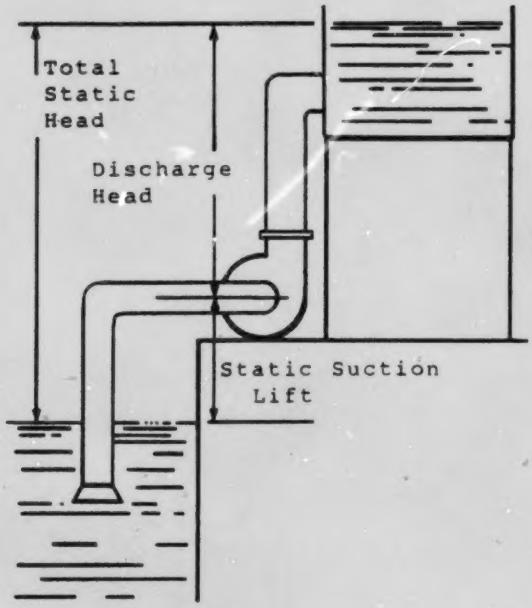


Figure 30-1-5. Discharge Head and Total Static Head with Negative Suction Head

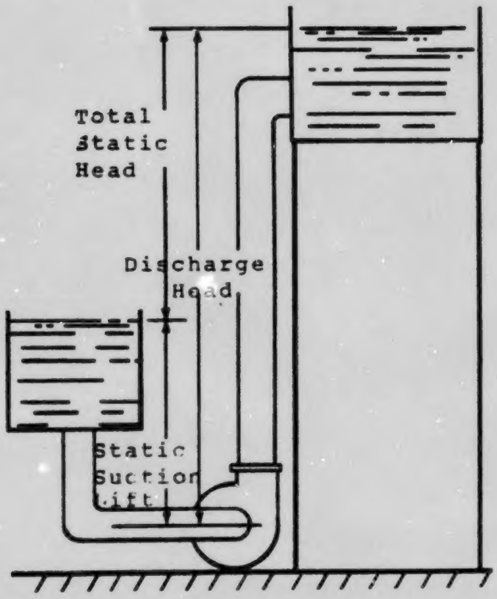


Figure 30-1-6. Discharge Head and Total Static Head with Positive Suction Head

CENTRIFUGAL PUMPS

Principle of Operation

A centrifugal pump imparts centrifugal force to the fluid as illustrated in Figure 30-1-7 to, to induce fluid flow. Centrifugal force acts to move a body away from its axis of rotation when the body is moving in a circular motion. This force gives kinetic energy to the fluid and a portion of the kinetic energy is then converted in the pump to static pressure or pressure head.

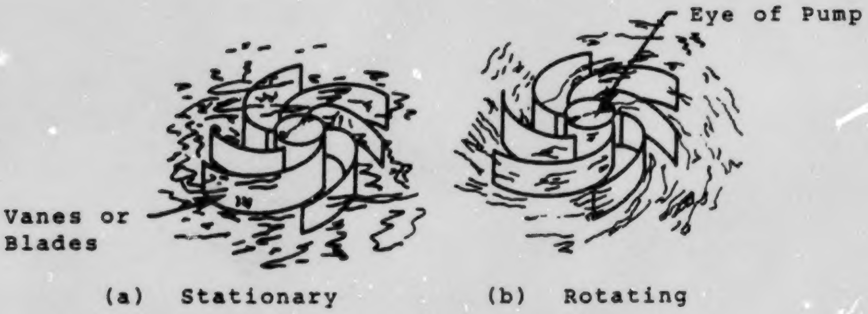

Eye of Pump
Vanes or Blades
(a) Stationary
(b) Rotating

Figure 30-1-7. Simplified Sketch of Centrifugal Action

Volute Centrifugal Pump

The volute centrifugal pump is comprized of an impeller and a casing of unique configuration. When the impeller is rotated, the fluid is slung outward into the space between the impeller and the casing. As illustrated in Figure 30-1-8, the outer edges of the impeller and the inner casing wall form a continuously divergent space. This divergent space, or volute, causes a portion of the kinetic energy of the fluid to be converted to pressure as the velocity of the fluid slows. In Figure 30-1-8, the divergent spacing is continued to the discharge point. Thus, at the exit from the discharge nozzle a velocity head and a pressure head has been imparted by the pump.

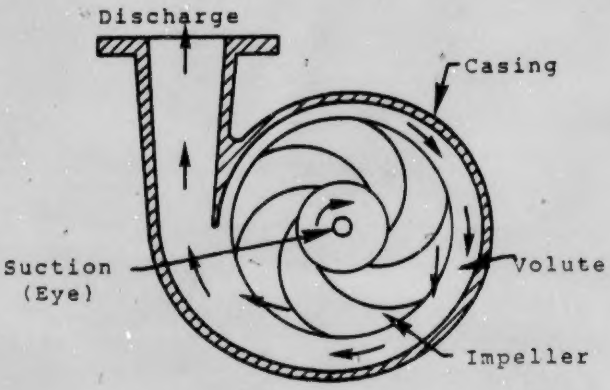

Discharge
Casing
Suction (Eye)
Volute
Impeller

Figure 30-1-8. Volute Type Centrifugal Pump

Diffuser type Centrifugal Pump

Diffuser centrifugal pumps use stationary guide vanes (diffuser) which surround the impeller. As illustrated in Figure 30-1-9, the curvature of the diffuser vanes form a divergent space. This divergent space converts some kinetic energy of the fluid to pressure head in the same manner as the volute. Further conversion of kinetic energy to pressure occurs in the divergent nozzle.

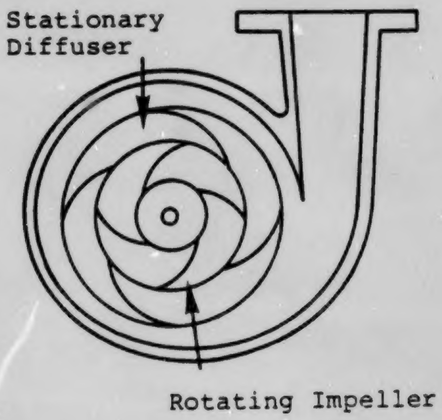


Figure 30-1-9. Diffuser Type Centrifugal Pump

Radial Flow Centrifugal Pumps

Centrifugal pumps are also classified by direction of fluid flow with respect to the impeller. If the pumped fluid flows outward, away from the impeller shaft, the pump is a radial flow pump. The volute pump and the diffuser pump illustrated in Figures 30-1-8 and 30-1-9 are radial flow pumps.

Axial Flow Centrifugal Pumps

If the pumped fluid flows along the axis of the impeller shaft, it is an axial flow pump. The vanes of an axial flow pump are shaped similar to the propeller vanes of an outboard motor. Figure 30-1-10 illustrates a typical axial flow type centrifugal pump. Axial flow pumps offer higher flow rates at lower pump heads than radial flow pumps.

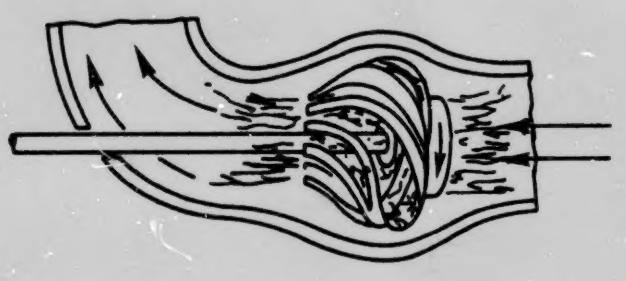


Figure 30-1-10. Axial Flow Centrifugal Pump

Mixed Flow Centrifugal Pumps

A centrifugal pump that combines both radial and axial flow is classified as a mixed-flow centrifugal pump. In this type of pump, as shown in Figure 30-1-11, the fluid enters the impeller in the axial direction and discharges in both the axial and radial directions.

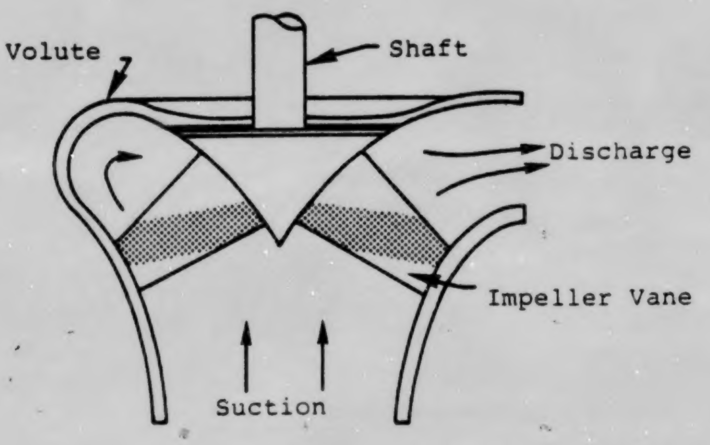


Figure 30-1-11. Mixed Flow Centrifugal Pump

Mixed flow centrifugal pumps are frequently used for circulating water pumps. In this application, the pumps are installed vertically with the suction submerged in water at all times. Large flow rates at a medium pump head and low rotational speed are provided by mixed flow centrifugal pumps.

Double Suction Centrifugal Pumps

Centrifugal pumps which have two radial flow impellers mounted back-to-back are classified as double flow or double suction centrifugal pumps. In a double suction centrifugal pump, the fluid flows in through two suctions but out a common discharge line. This arrangement offers higher flow capacity with little increase in pump head.

Multi-Stage Centrifugal Pumps

Centrifugal pumps are further classified by number of stages. A stage consists of one combination of suction and discharge. A centrifugal pump with one impeller is a single stage pump. In a multistage centrifugal pump, the first impeller discharges to the suction of the next impeller and so on for as many stages as the pump has. Multistage pumps are used to provide a given flow rate at a higher discharge head.

Shaft Seals

Centrifugal pumps require a seal between the pump shaft and the shaft penetration into the pump casing. Otherwise, serious leakage will occur.

The method of sealing the shaft is dependent on the size of the pump, the pressure of the fluid being pumped, and the temperature of the fluid being pumped. Figure 30-1-12 illustrates the simplest type of pump seal, i.e., the stuffing box. A stuffing box shaft seal is typically used when pumping low pressure fluids The stuffing box consists of an annular space in the pump casing where rings of packing

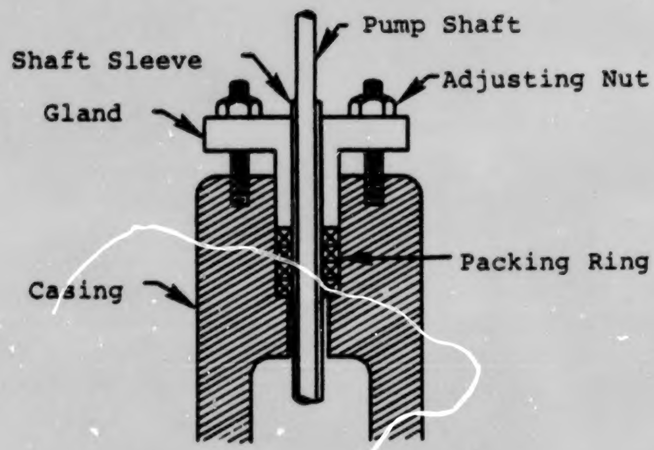


Figure 30-1-12. Stuffing Box Shaft Seal

material are placed. The packing rings are held in place by a packing gland or follower that is bolted to the pump casing. As the adjusting nuts are tightened, the packing gland compresses the packing material radially against the shaft to form a tight seal. The shaft sleeve shown in Figure 30-1-12 provides excess material to permit wear without degrading the strength of the shaft. Cooling and some lubrication of the seal is needed to prevent overheating the packing material. Lubrication and cooling can be provided by loosening the gland slightly to permit a small quantity of fluid to leak along the shaft. Another method is forced lubrication and cooling as illustrated in Figure 30-1-13. Forced cooling is used if the pump suction is under a vacumn such that outward leakage is impossible or when the fluid being pumped is too hot to provide adequate cooling. In this case, a supply of clean, cool water is supplied to the stuffing box to provide adequate cooling and lubrication. This water, called gland cooling or gland sealing water, is injected through a drilled passage in the pump casing to a lantern ring located in the middle of the

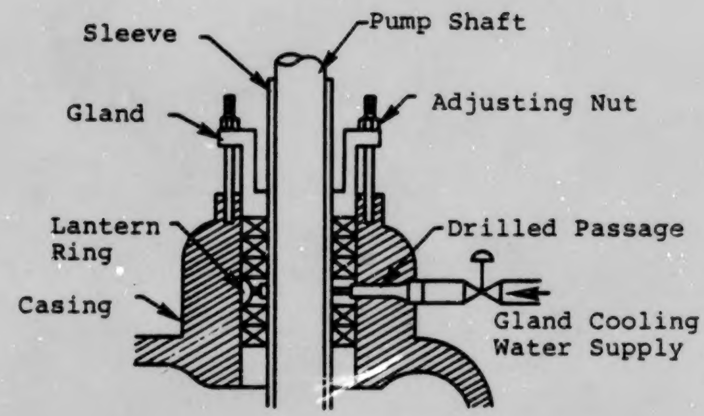

Sleeve
Pump Shaft
Gland
Adjusting Nut
Lantern Ring
Drilled Passage
Casing
Gland Cooling Water Supply

Figure 30-1-13. Water Cooled Shaft Seal

stuffing box. The lantern ring distributes the sealing water around the shaft to provide the required cooling and lubrication.

Packing used for pump shaft seals may be any of the six styles illustrated in Figure 30-1-14. These styles are diagonal braid, twist, plait, laminate, braid, and wrap.

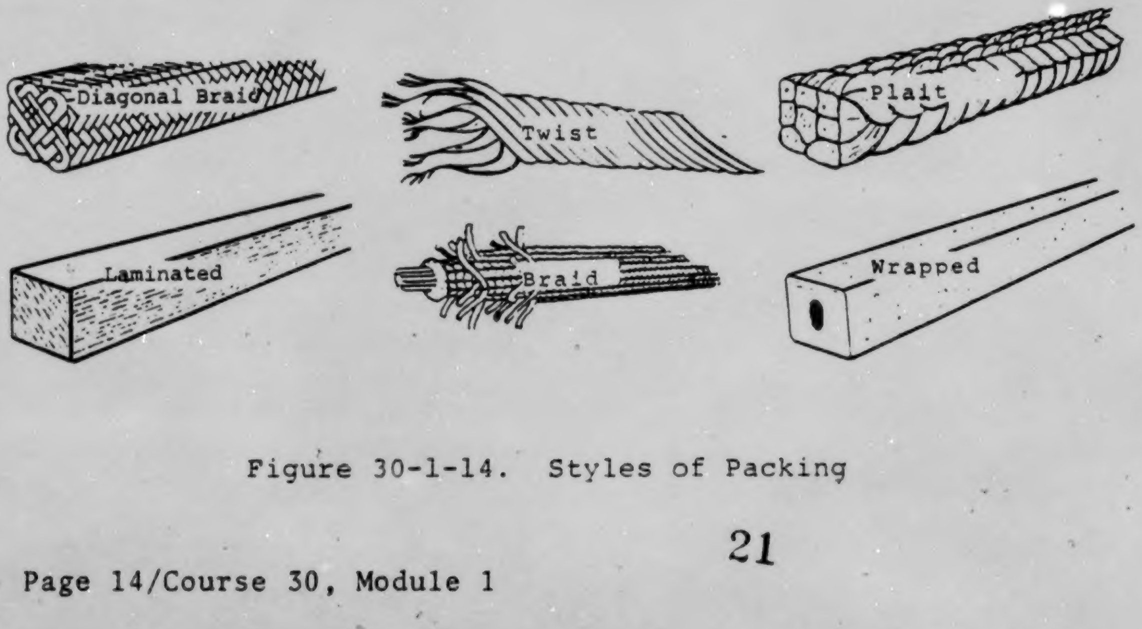

Diagonal Braid
Twist
Plait
Laminated
Braid
Wrapped

Figure 30-1-14. Styles of Packing

Canned Pumps

Some pumps in nuclear power plants pump fluid that is potentially radioactive. Leakage from these pumps is carefully controlled. One type of pump used in this case is the canned pump which is illustrated in Figure 30-1-15.

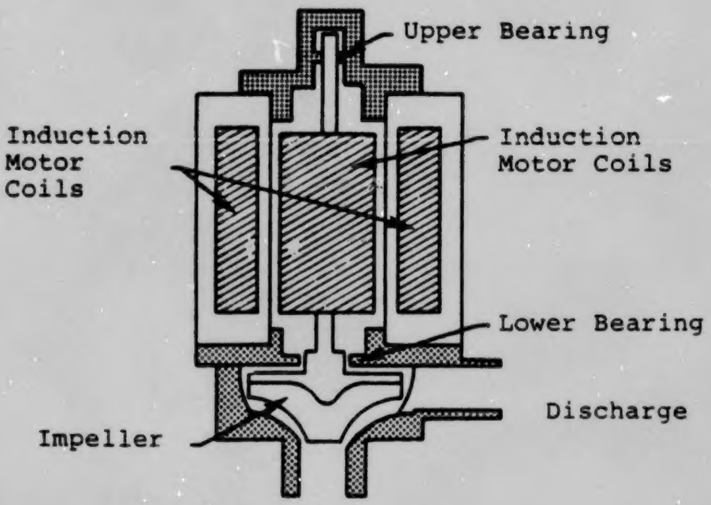

Upper Bearing
Induction Motor Coils
Induction Motor Coils
Lower Bearing
Discharge
Impeller

Figure 30-1-15. Canned Pump

In the canned pump, the prime mover is encapsulated (canned) and seal welded to the pump casing. The prime mover (an induction motor) is cooled and lubricated by a portion of the fluid being pumped which is circulated along the shaft and between the rotor and stator cans. This fluid also lubricates the motor bearings.

JET PUMPS

Principle of Operation

Jet pumps are dynamic pumps which do not have moving parts. Instead a high velocity fluid serves as the prime mover. The basic jet pump is illustrated in Figure 30-1-16.

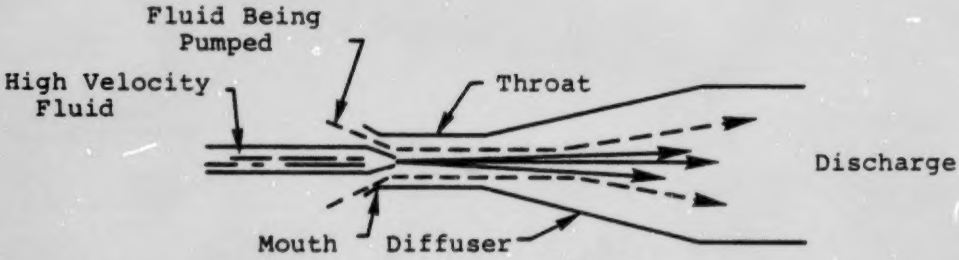


Figure 30-1-16. Jet Pump

Referring to Figure 30-1-16, a high velocity fluid is directed through a nozzle toward a diffuser. The high velocity fluid impinges on the fluid to be pumped and carries it along with the high velocity fluid. This process is termed "entrainment". As the entrained fluid is carried out of the throat of the diffuser, a low pressure area is created around the mouth of the diffuser. This establishes a differential pressure that forces more of the fluid to be pumped into the diffuser where it is entrained, thus continuing the process. The divergent section of the diffuser converts a portion of the kinetic energy to pressure or pump head.

DISPLACEMENT PUMPS

Principle of Operation

Displacement pumps move a specific quantity of fluid with each pumping cycle. These pumps entrap a quantity of fluid at the pump suction and physically move it to the pump discharge. As long as the prime mover operates the displacement pump, fluid is pumped into the discharge regardless of discharge pressure. If the speed of operation of the displacement pump is constant, the fluid flow rate is consatnt regardless of discharge pressure. Two types of displacement pumps are common: the reciprocating positive displacement pump and the rotary positive displacement pump.

Reciprocating Positive Displacement Pump

A simplified sketch of the reciprocating positive displacement pump is provided by Figure 30-1-17.

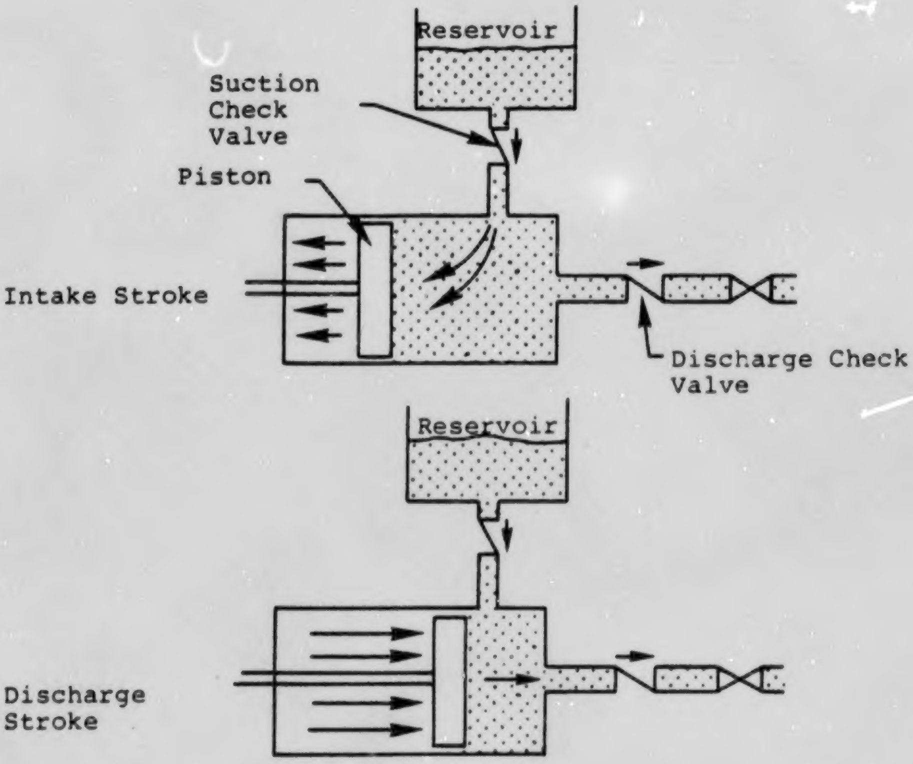

Reservoir
Suction Check Valve
Piston
Intake Stroke
Discharge Check Valve
Reservoir
Discharge Stroke

Figure 30-1-17. Reciprocating Positive Displacement Pump

As illustrated in Figure 30-1-17, the intake stroke occurs as the piston moves to the left. During the intake stroke, the suction line check valve opens allowing fluid to enter the cylinder. As the piston moves to the right, in Figure 30-1-17, the suction check valve is forced closed and the discharge check valve is forced open by the displacement of the fluid. The piston physically pushes the fluid into the discharge. This type of positive displacement pump is known as single-acting because the fluid is forced into the discharge piping only with one motion of the piston and not on the other motion of the piston. Reciprocating pumps are also designed to have suction and discharge valves which allow pump discharge on both motions of the piston. Such pumps are double-acting positive displacement pumps.

Rotary Positive Displacement Pump

A second type of positive displacement pump is the rotary pump. The rotor may be lobes or gears. Figure 30-1-18 illustrates a typical rotary gear pump.

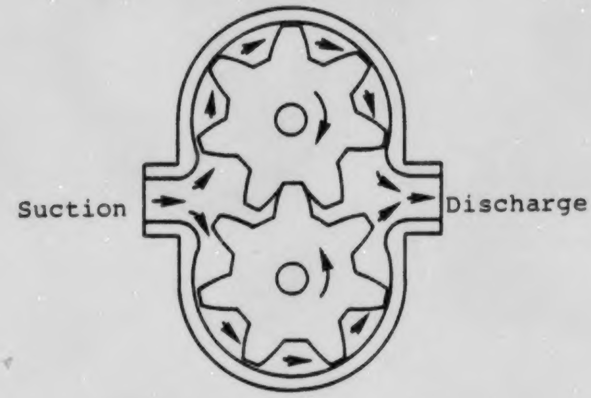


Figure 30-1-18. Rotary Gear Pump

In the gear pump, the fluid being pumped is trapped between the gear teeth and the pump casing. As the gears rotate, the fluid is physically carried around to the pump discharge. The discharge fluid flow is much less pulsating than with a reciprocating pump and may be considered as smooth, constant flow.

PUMP INSPECTION SPECIFICATIONS

Pump Design Specification

The nuclear power plant owner, or a contractor thereto, develops a design specification for each type of pump to be used in the nuclear plant. The design specification stipulates the type of pump and all its design features. It is applied to the manufacturer of the pump who must deliver pumps which meet the requirements of the design specification.

Inspection activities of the owner use the requirements of the pump design specification, including engineering drawings which are referenced thereby, as the acceptance criteria for inspections at the manufacturer's plant or at receipt of the delivered pump. The owner's quality control department may directly perform the inspections or the owner may contract for inspection services. In either case, inspections are planned and conducted to confirm that delivered pumps conform with the pump design specification.

System Design Specification

The nuclear power plant owner, or a contractor thereto, develops a design specification for each system of the plant. The system design specification stipulates the types of components which will comprise the system, criteria to be met while installing the system, and system functions and limits during normal, shutdown, and emergency condition of operation.

Inspection activities of the owner use the requirements of the system design specification and pump design specification as acceptance criteria for inspections during installation, preoperational testing, and operational activities. The owner's quality control department or a contractor may perform the inspections. In either case, inspections are planned and conducted to confirm that pumps are installed, tested, and operated in accordance with the system and pump design specifications.

Quality Assurance Standard

Quality assurance requirements for installation, inspection and testing of pumps are specified by an American National Standard. This standard is ANSI N45.2.8, "Supplementary Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems for the Construction Phase of Nuclear Power Plants". While the title of this standard indicates it is applicable to construction, it provisions are also used, as applicable, in the operations phase of the plant.

ANSI N45.2.8 requires the planning for and implementation of inspections of pumps during three major evolutions. These evolutions are (1) preinstallation verifications, (2) control of installation process, and (3) installed system inspections and tests.

PREINSTALLATION INSPECTION

Purpose and Scope

Preinstallation inspections of pumps verify that the pump and the installation area comply with specified requirements. When a pump is received at the nuclear power plant site, it is receipt inspected for conformance with the pump design specification. Accepted pumps are tagged with an acceptance tag and placed in storage until it is needed for installation. Preinstallation inspection confirms that the identity and condition of the pump is maintained. Installation areas are inspected to confirm that procedures, trained personnel, and installation equipment are available as required by the system design specification and installation drawings. These installation inspections are applied to (1) identification, (2) processes and procedures, (3) pump physical conditions, and (4) site conditions.

Identification Inspections

The installation contractor must establish a quality assurance program which ensures items are properly installed into their correct location or specified by installation drawings. The quality assurance program provides for maintaining lists or procedures which designate the exact components to be installed in a given system. At release of a pump from storage to the installation area, the inspection activity confirms that the designated pump is in fact released.

Pump identification is provided by the name plate and the accept tag. The data on the name plates are verified as correct by receiving inspection and thereafter the name plate is used as acceptable indication of pump identity. The pump design specification stipulates what is required on the name plate. It typically requires (1) name of system for which the pump is intended, (2) pump manufacturer's name, (3) type of pump, (4) size of pump, (5) flow capacity, (6) pump head rating, and (7) serial number of the pump. An example name plate is illustrated in Figure 30-1-19.

Ingersoll Rand

System:	Core Spray	Type:	Centrifugal
Size:	10 x 14	Flow:	3400 gpm
Serial:	365-187	Head:	450 feet

Figure 30-1-19. Sample Name Plate Data

Preinstallation inspectors compare name plate data and the accept tag data with the installation procedures to confirm that the correct pump is released for installation. Also, a roving inspector is typically assigned to periodically check released pumps to confirm that their identity is maintained.

Inspection of Processes and Procedures

Installation procedures and drawings are prepared for use by the installation contractor. For a given installation activity, the procedures and drawings applicable to that activity are collectively termed "job package". The job package may be attached to the component at release from storage or it may be issued to the supervisor of the installation group. The job package delineates all necessary instructions for installing an item such as a pump.

Preinstallation inspectors confirm that a complete job package is on hand and that its provisions are met. This inspection may be on a roving basis such that an inspector proceeds from one installation activity to another as checks are completed. Checks are typically made to verify (1) availability of approved procedures and drawings, (2) qualification of personnel as required, (3) compliance with prerequisites, (4) availability of necessary handling and fixturing devices, and (5) compliance with safety requirements.

- Approved procedures and drawings - In addition to to confirming that the correct job package is available, the inspector checks for other procedures which are required by the installation procedure or drawing. Such other procedures typically involve special processes which will be required for the installation work. Examples include welding procedures, cleaning procedures, heat treating procedures, and coating procedures.
- Qualification of personnel - The inspector confirms that persons assigned to the installation are qualified if formal qualification is required. Welders and nondestructive examination personnel are required to be qualified. Dimensional and visual inspectors may also be required to be qualified.
- Compliance with prerequisites - The installation procedure specifies any prerequisites which must be met prior to installing a pump. Examples include removal of packing and plugs which protected the pump internals, removal of protective coatings, and cleaning the general area.
- Handling and fixturing - Dependent on the type and size of pump, various handling equipment and fixtures are necessary for safe movement and positioning of the pump. The inspector verifies availability of such equipment as specified by the job package.
- Safety - The inspector verifies compliance with safety precautions stipulated by the job package. For pump installation, the safety requirements are typically those associated with routine installation activities such as use of hard hats and eye protection.

Inspection of Pump Physical Conditions

During the inspection of installation processes and procedures, the inspector also checks the physical conditions of the pump. These checks insure that (1) the quality of the pump has been maintained, (2) any prior reported nonconformances have been corrected, and (3) the pump is adequately clean for installation.

Checks on maintenance of pump quality look for physical damage from mishandling and for unique conditions applicable to the pump. Examples of unique conditions are:

- Weld and preparations are undamaged for pumps which will join suction or discharge piping by welding.
- Excessive rusting has not occurred.
- Inert gas blankets, when required for canned pumps, have been maintained.
- Protective caps and plugs are kept in place until installation begins.

Inspection of Site Conditions

During the inspection of installation processes and procedures, the inspector also checks site conditions for compliance with the requirements of the job package. These checks verify that site conditions have been established as required to avoid adversely affecting the quality of the pump. Examples include:

- Protection from adjacent installation activities such that there is little risk of damage to the pump.
- Protection from inclement weather such as snow, rain, sleet, etc.
- Installation of permanent or approved temporary supports on which the pump will be mounted.
- Required maintenance of the pump has been performed, such as checking lube oil level in a reciprocating pump.

INSTALLATION INSPECTION

Purpose and Scope

While reinstallation inspections verify readiness to proceed with installation, installation inspections verify that required quality is obtained by the installation work. To accomplish this purpose, critical steps in the installation process are selected for inspection and other installation steps are inspected on a roving basis. These inspections encompass (1) control of procedures and processes, (2) nondestructive examinations, (3) work in progress, and (4) final installation.

Control of Procedures and Processes

Inspections on the control of procedures and processes verify that established controls are being implemented throughout the installation time cycle. These inspections are typically performed on a roving basis and check for procedural compliance by the various steps of installation work. These inspections typically check for (1) control of revisions to procedures and drawings, (2) use of approved procedures and materials by qualified personnel, (3) indication of quality status, (4) compliance with sequence, (5) control of nonconformances, (6) recording as-builts, and (7) completeness of inspections and tests:

- Control of revisions to procedures and drawings - drawings contained or referenced by the job package may require revision for a number of reasons. Whenever a job package has been released to the installation contractor, any subsequent revision to applicable procedures or drawings must result in providing to the installation contractor the revised document. Installation inspections confirm that the latest approved revision levels of procedures and drawings are in use by the installation contractor.
- Use of qualified personnel, procedures, and materials -

Installation inspections confirm that personnel actually performing the work are qualified as required, that procedures in use are qualified or approved, and that materials being used are those specified by the procedures and drawings. Examples of materials include threaded fasteners, welding materials, shims, and shaft packing.

- Indication of quality status - As installation proceeds, the status of installation including inspections and tests must be clearly identifiable. Such indication of status may be provided by inspection reports, tagging the pump, or signoff of installation check lists. The installation inspector confirms that indication of quality status is maintained.
- Compliance with sequence - The job package includes the sequence of steps for proper installation, inspection and test of pumps. The installation inspector verifies compliance with the specified sequence.
- Control of nonconformances - Inspections and tests required by the job package may identify nonconforming conditions. In such cases, the pump is tagged as nonconforming and a nonconformance report is initiated. Engineering determines what correction of the nonconformance is necessary and issues appropriate instructions. Until completion of the correction, the pump status must be maintained as nonconforming. The installation inspector verifies the tagging of nonconforming pumps and maintenance of such tagging until the nonconformance is corrected.
- Recording of as-builts - The job package may require that certain dimensions be recorded to reflect the as-built values of the installed pump. For example, the actual, installed location of the pump discharge

nozzle with respect to a datum may be needed to permit fabrication of a piping assembly which will eventually connect to the pump discharge. The installation inspector verifies that required as-built information is recorded as installation progresses.

- Completeness of inspection and test - The job package stipulates the inspections and tests to be performed during the installation process. The installation inspector verifies that inspection and test reports are prepared for each required inspector and test.

Nondestructive Examinations

Nondestructive examinations of pump installations are typically required only for welded joints such as welds between suction and discharge piping and the pump. Because many pumps have bolted flange connections to piping as well as bolted support mounts, nondestructive examinations may consist of liquid penetrant, magnetic particle, radiography or ultrasonic tests. For weld joints in magnetic materials, magnetic particle and radiography are typically required. For weld joints in nonmagnetic materials, liquid penetrant and radiography are typically required. For welds which are subject to later inservice inspection by ultrasonic testing, an ultrasonic test is performed at installation to establish a known "base-line" for comparison with later inservice ultrasonic tests. Whenever nondestructive testing is required, it must be performed to an approved procedure by qualified persons.

Work in Progress

Installation inspections are planned for work in progress to ensure that critical installation requirements are met. For critical requirements, inspection hold joints are established which require installation work to stop at such points until the inspection is performed. For installation work steps considered not critical, a roving inspector periodically checks for compliance with the job package. Typical hold points for pumps include:

- Orientation - Inspection verifies that the pump is mounted with suction, discharge, and prime mover connections in the correct orientation.
- Levelling and alignment - Inspection verifies that requirements for levelling and alignment are met. The alignment between the prime mover and the pump shaft is of particular importance.
- Torquing of threaded fasteners - Bolted mounts, pipe-to-pump flanges, and pipe hangers are torqued to specified values. The installation inspector typically witnesses torquing of threaded fasteners.
- Shaft seals or packing - For pumps having mechanical seals, the installation inspector witnesses the installation and adjustment of the seals. For pumps having flexible peaking, pump manufacturer typically installs the packing but does not fully compress it. The installation inspector witnesses the tightening of compressible shaft packing to verify torquing to a specified value.
- Fluid levels - The prime mover may contain reservoirs for lubricating oils or may require certain lubrication at installation. The installation inspector checks for compliance with specified requirements for lubrication and any other maintenance item which may be required.

The remainder of installation work is typically checked by a roving installation inspector. Such addition work activities include cleaning, welding, pipe fitting, housekeeping, and protection of pump intervals from foreign materials.

Final Installation Inspection

Once the pump is installed, the installation inspector makes a final inspection which serves to report the acceptance of the installation. The final inspection verifies that:

- All steps of the job package have been completed including all inspections and tests and correction of any nonconformances.
- External connections have been completed including piping, cooling water, lubrication lines, and power connections as required.
- Prime mover rotation is correct.
- Limit switches, interlocks, and stops are installed.
- All designated mounts, hangers, and supports are installed.
- All designated temporary protective plugs, covers, and strainers are in place.

At this point, installation inspection has verified that the correct pump has been properly installed in the right location. The pump is now ready for preoperational tests. However, the entire system which contains the pump must typically be installed prior to conducting preoperational tests.

PREOPERATIONAL TESTS

Types

Preoperational tests for pumps basically consist of either integrity tests or functional tests. Integrity tests are those which check the physical condition of the pump. Functional tests are those which check the operating performance of the pump. Integrity tests for pumps consist of hydrostatic testing and seal leakage testing. Functional tests are described in Module 30-2 of the Mechanical Inspection Course.

Hydrostatic and Seal Leakage Testing

Hydrostatic and seal leakage tests are typically performed as one integrated test. The pump may be tested as an individual component but most often is tested in conjunction with testing the system which employs the pump. Detailed test procedures are used for conducting these tests.

Prior to conducting integrity tests, established prerequisites must be met. These prerequisites typically include flushing the system to achieve the specified level of cleanliness and removing or installing temporary protective devices such as plugs, blanks, and screens.

Hydrostatic testing requires the filling of the pump with water and pressurizing the water to a specified value. Specified test pressures are typically 120% of design pressure of the pressure boundary parts. With the pump filled and pressurized to test pressure, an inspector visually checks for evidence of leaks. Acceptance criteria is typically no evidence of leaks other than design leakage along the pump shaft. Leaking connections are retorqued or replaced as necessary to eliminate leaks.

Shaft seal leakage tests typically immediately follow the visual inspection of the hydrostatic test. With the pump still at test pressure, shaft seal leakage is measured. Measurement of shaft seal leakage typically involves the use of a coffer dam around the shaft and plastic tubing to drain the leakage. The leakage is collected for a timed interval in a graduated beaker. Leak rate is calculated by dividing the volume collected by the collection time. Leak rate is normally in units of cubic centimeters per hour. Where limits on shaft seal leak rate are exceeded, the seal is either adjusted or replaced to bring the leak rate within limits.

EXERCISES

The following exercises serve to reinforce the information presented in this module.

A. Perform the following exercises on Fundamental Pump Design, Centrifugal Pumps, Jet Pumps and Displacement Pumps presented in this module. Answers to these exercises are presented at the end of this section.

1. What are the two classifications of pumps based on the principles of adding energy to the pump fluid?
   a.
   b.

2. Define:
   a. Static suction lift

   b. Static suction head

   c. Discharge head

   d. Total static head

3. Briefly describe the principle of operation of:
   a. single stage, radial flow, centrifugal pump

   b. jet pump

   c. single acting reciprocating displacement pump

4. Describe the centrifugal pump classifications of:
    a. radial flow

    b. axial flow

    c. mixed flow

    d. multi-state

    e. canned

5. Describe two methods of lubricating and cooling compressible shaft seals for centrifugal pumps.
    a.

    b.

6. Briefly describe the operation of a rotary gear pump.

7. Describe how pump suction and discharge pressure units in feet, give a meaningful measurement.

Check your answers to the Part A Exercises on Fundamental Pump Designs, Centrifugal pumps, Jet Pumps and Displacement Pumps as follows:

1. a. Dynamic
    b. Displacement

2. a. Static suction lift is the vertical distance in feet from the level of the fluid supply below the pump to the axis of the pump.
   b. Static suction head is the vertical distance in feet from the level of fluid supply above the pump to the axis of the pump.
   c. Discharge head in the vertical distance in feet above the axis of the pump to which the discharge fluid would rise in a free-standing column.
   d. Total static head is the absolute difference between discharge head and suction head, or, it is the vertical distance in feet between the levels of fluid from discharge to suction.

3. a. The single stage, axial flow centrifugal pump adds kinetic energy to the fluid by centrifugal action caused by impeller rotation. A portion of the kinetic energy is converted to pressure in the divergent volute.
   b. The jet pump uses a high velocity fluid to impinge on the fluid to be pumped. The entrained fluid creates a low pressure point which permits more fluid to be entrained. A portion of the entrained fluid's kinetic energy is converted to pressure in a divergent discharge nozzle.
   c. A single acting reciprocating displacement pump pulls fluid into a cylinder on the intake stroke and physically forces fluid out the discharge on the discharge stroke. Check valves are arranged to permit fluid flow only in the desired direction during each stroke.

4. a. Radial flow is a classification of centrifugal pump where the pumped fluid flows radially outward from the impeller shaft.

   b. Axial flow is a classification of centrifugal pump where the pumped fluid flows along the axis of the impeller shaft.
   c. Mixed flow is a classification of centrifugal pump where the pumped fluid flows both radially and axially with respect to the impeller shaft.
   d. Multi-stage centrifugal pumps are two or more impellers where the first impeller discharges to the suction of the next impeller and so on for the number of impellers included.
   e. Canned centrifugal pumps have the prime mover sealed to the pump such that leakage along the impeller shaft cannot escape from the cans to the surroundings.
5. Two methods of cooling and lubricating compressible shaft packing are:
   a. shaft leakage of the fluid being pumped
   b. an external supply of water to the seal.
6. The rotary gear pump physically entraps fluid between gear teeth and the pump casing. As the gears rotate, fluid is carried around the inside of the casing to the discharge outlet.
7. Pump pressure units in feet is meaningful because of the direct correlation between level of fluid in feet and the pressure exerted by such level caused by gravitational acceleration on that fluid.

B. Perform the following exercises on Preinstallation, Installation and Preoperational Inspection as follows:

1. What is the purpose of preinstallation inspections?

2. Briefly describe the preinstallation inspections associated with.
   a. identification

   b. processes and procedures

   c. pump physical conditions

   d. site conditions

3. What is the purpose of installation inspections.

4. Briefly describe the installation inspections associated with:
   a. control of procedures and processes

   b. nondestructive examinations

   c. work in progress

   d. final installation

5. Name two preoperational tests for physical integrity of a pump.
   a.
   b.

6. Describe how to conduct a shaft seal leakage test.

7. Name five data items typically required to be on pump nameplates.

Check your answers to the Part B Exercises on Preinstallation, Installation, and Preoperational Inspections as follows:

1. The purpose of preinstallation inspections is to verify that the pump and the installation area comply with specified requirements.
2. a. Identification inspections check name plate data and presence of an accept tag to ensure that the pump released for installation is the correct pump and was accepted by receipt inspection.
   b. Process and procedures inspections verify availability of approved drawings and procedures, qulaification of personnel, compliance with prerequisites for installation, availability of

handling equipment and fixturing, and compliance with safety requirements.

c. Inspections of pump physical conditions verify that the quality of the pump is maintained, prior reported nonconformances are corrected, and the pump is adequately clean.

d. Inspection of site conditions verify that site conditions are established such that the quality of the pump is not adversely affected. Checks are made on adjacent work activities, protection from inclement weather, installation of mounts, and performance of maintenance.

3. The purpose of installation inspection is to verify that required quality is obtained by the installation work.

4. a. Inspection of the control of procedures and processes verify the control of revisions to procedures and drawings, use of approved procedures and materials by qualified personnel, identification of quality status, compliance with sequence, control of nonconformances, recording of as-builts, and completeness of inspections and tests.

b. Nondestructive examinations are inspections of welded joints for the purpose of determining acceptance of the weld and establishing base line data for later inservice inspections.

c. Inspections of work in progress are comprised of hold points and random inspections. Inspections at hold points include checks for orientation, levelling and alignment, torquing, shaft sealing, and fluid levels. Random inspections periodically check for compliance with the remainder of installation work such as welding, cleaning, fitting, housekeeping, and physical protection of pump internals.

d. Final installation inspection verifies that all steps of the job package have been successfully completed, external connections have been made to the pump, prime mover rotation is correct, limit switches and interlocks have been installed, and mounts, hangers, and supports have been installed.

5. Two preoperational physical integrity tests are hydrostatic tests and shaft seal leakage tests.

6. A shaft seal leakage test is conducted with the pump pressurized with water to a specified value. The leakage along the shaft is collected and measured for a timed interval. Dividing the volume collected by the time interval gives the leak rate.

7. Pump name plates typically give:

   a. manufacturer's name
   b. type of pump
   c. size of pump
   d. flow capacity
   e. pump head
   f. name of system receiving the pump
   g. serial number.

MATERIALS

There are no required materials for this module.

PROCEDURES

There are no required procedures for this module.

DATA TABLE

There are no required data tables for this module.

REFERENCE MATERIALS

ASME, ANSI N45.2.8, Supplementary Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems for the Construction Phase of Nuclear Power Plants, The American Society of Mechanical Engineers, New York, N.Y., 1975

ASME, Boiler and Pressure Vessel Code, Section III, The American Society of Mechanical Engineers, New York, N.Y., 1978

Krutzsch, William C., Pump Handbook, McGraw Hill, 1976

TEST

A. Answer the following questions as being either True or False:

____ 1. Two major classifications of pumps by principal of adding energy to the fluid are dynamic and displacement.

____ 2. Dynamic pumps include positive displacement pumps and jet pumps.

____ 3. Centrifugal pumps add kinetic energy to the fluid by the rotation of an impeller and convert a portion of the kinetic energy to pressure in the volute.

____ 4. Jet pumps may be of axial flow, radial flow or mixed flow subclassifications.

____ 5. Centrifugal pumps may be single stage, multi-state or double suction.

____ 6. Jet pumps use the kinetic energy of a high velocity fluid to entrain the fluid to be pumped. Entrainment creates a lower pressure which promotes fluid flow. A portion of the kinetic energy is converted to pressure in the divergent nozzle discharge section of the jet pump.

____ 7. Displacement pumps include reciprocating and rotary positive displacement pumps.

____ 8. The advantage of a positive displacement pump is that it is designed to pump both water and steam.

____ 9. Displacement pumps physically carry a quantity of fluid from suction to discharge.

____ 10. Reciprocating positive displacement pumps may be single acting, double acting, or reverse flow types.

____ 11. Rotary positive displacement pumps may be gear or lobe types.

____ 12. Static suction head is the vertical distance in feet from the level of the fluid supply to the axis of the pump. When the level of supply is below the pump, the term is usually referred to as static suction lift.

____ 13. Discharge head is the vertical distance in feet from the pump axis to the sea level elevation.

____ 14. Total static head is the absolute difference between discharge head and suction head, or, the vertical distance in feet from the level of discharge fluid to the level of suction fluid.

____ 15. The principle specifications which provide acceptance criteria for pump inoperation are the pump design specification and the system design specification, including associated design and installation drawings.

____ 16. Quality assurance provisions for pump installation, inspection and testing are given by the American Pump Installation Society Procedure N45.2.8.

____ 17. Preinstallation inspections verify that the pump and the installation area comply with specified requirements.

____ 18. Preinstallation inspections are applied to pump identification, processes and procedures, pump physical condition, and site condition.

____ 19. Installation inspections encompass control of procedures and processes, nondestructive examinations, work in progress, and final installation.

____ 20. Preoperational integrity tests are hydrostatic and shaft seal leakage tests.

B. Answer the following questions.

1. Define or briefly explain the following terms:
   - a. Static suction lift
   - b. Discharge head
   - c. Radial flow
   - d. Centrifugal pump
   - e. Mixed flow
   - f. Velocity head
   - g. Cavitation
   - h. Minimum net positive suction head (MNPSH)
   - i. Volute
   - j. Shaft seals
   - k. Entrainment

2. Match the following specifications listed in the left-hand column with the purpose given in the right-hand column.

Specification	Purpose
___ 1. Pump Design Specification	a. Provides quality assurance requirements for the installation, and testing of pumps.
___ 2. System Design Specification	b. Provides guidelines to the owner for selecting the types of pumps for use.
___ 3. ANSI N45.2.8	c. Provides criteria which must be met by the manufacturer of the pump.
	d. Stipulates the components and functions of a system and the criteria to be met during installation of the system.

3. What is the purpose of preinstallation inspections?

4. Briefly describe the preinstallation inspections associated with:
   a. identification

   b. processes and procedures

   c. pump physical conditions

   d. site conditions

5. What is the purpose of installation inspections.

6. Briefly describe the installation inspections associated with:
   a. control of procedures and processes

   b. nondestructive examinations

   c. work in progress

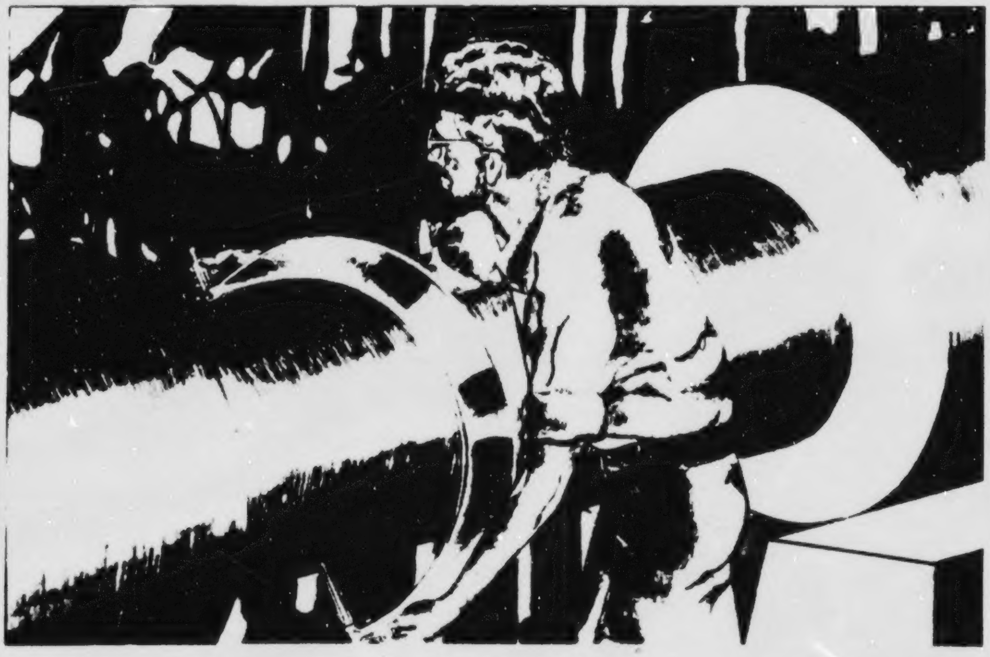
   d. final installation

7. Name five data items typically required to be on pump nameplates.

NUCLEAR TECHNOLOGY

MODULE 30-2

PUMP FUNCTIONAL TESTING



COURSE 30 MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

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COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

MODULE 30-1	Pump Inspection
MODULE 30-2	Pump Functional Testing
MODULE 30-3	Valve Inspection
MODULE 30-4	Piping Inspection
MODULE 30-5	Sufrace Cleaning Inspection
MODULE 30-6	Protective Coating Inspection
MODULE 30-7	Pressure Vessel Inspection
MODULE 30-8	Rotating Equipment Inspection

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INTRODUCTION

The Nuclear QA/QC Technician is intimately involved with pump functional testing. The technician witnesses key portions of tests to verify proper conduct of tests. The technician reviews test reports for completeness. And, the technician monitors testing performance to ensure use of correct procedures, calibrated test equipment, use of qualified test persons, compliance with test prerequisites, and proper acceptance of test results.

This module describes typical pump functional tests which are performed after pump installation and prior to release of the plant for unrestricted power operation. During this time interval, tests are typically classified as preoperational, cold functional, hot functional, and start-up. These phases of testing are defined and the types of pump tests in each are described.

Primary emphasis is given to specific pump functional tests. Purpose of each test is stated and methods of conducting the tests are described. Prior to presenting these specific tests, this module summarizes performance characteristics of centrifugal pumps and reciprocating pumps. This summary should assist in the understanding of the specific pump tests.

MODULE PREREQUISITES

Knowledge of types of pumps and their fundamental principles of operation and knowledge of pressure and flow detection and measurement systems are required. The student/trainee should have completed Module 31-1 of this course.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Define the terms capacity, pump head, output power, brake horsepower, and pump efficiency as they relate to centrifugal pumps.
2. Define the terms capacity, displacement, and slip as they relate to reciprocating pumps.
3. Recognize typical performance curves for centrifugal pumps and relate pump operating conditions to the curves.
4. Define cavitation and describe how it is avoided.
5. Describe the interrelationships of capacity, discharge pressure, pump speed, and discharge throttle valve settings for a reciprocating positive displacement pump.
6. State the purpose of and briefly describe how to conduct any of the following individual pump tests:
    a. direction of rotation
    b. vibration
    c. motor load versus time
    d. seal leakage
    e. seal cooling
    f. flow and pressure characteristics
    g. acceleration
    h. coastdown
7. State the purpose of and briefly describe how to conduct the following types of pump systems tests:
    a. start-stop functions
    b. variable speed functions
8. Briefly describe the type of information provided by pump functional test procedures in any of the following sections of the procedure:
    a. title, number, and revision
    b. test objectives
    c. test equipment

d. limitations
e. prerequisites
f. procedure, notes, and cautions
g. acceptance criteria

CENTRIFUGAL PUMP CHARACTERISTICS

Definitions

Principle terms associated with the operating characteristics of centrifugal pumps are pump capacity, pump head, output power, brake horsepower, and pump efficiency. Definitions of these terms and their symbols are:

- Pump capacity - The volume of fluid per unit time delivered by the pump. Capacity is represented by the symbol Q and is expressed in gallons per minute (gpm) or cubic feet per second (ft^3/sec).
- Pump head - The net work done on a unit weight of fluid in passing from the suction to the discharge. Head is represented by the symbol H and is expressed in units of feet.
- Output Power - The liquid horsepower delivered by the pump to the fluid. Output power is expressed as liquid horsepower and symbolized by lhp.
- Brake horsepower - the horsepower delivered by the prime mover to the pump shaft. Brake horsepower is symbolized by bhp.
- Pump efficiency - The ratio of output power to input power, re, the ratio of liquid horsepower to brake horsepower. It is expressed as percentage and symbolized by η.

Head Versus Capacity

The centrifugal pump adds kinetic energy to the fluid by the rotation of the pump impeller. A portion of the kinetic energy is converted to pressure in the volute. In order to introduce the relationship between head and capacity, a simplified description of these effects is presented using the pump illustrated in Figure 30-2-1.

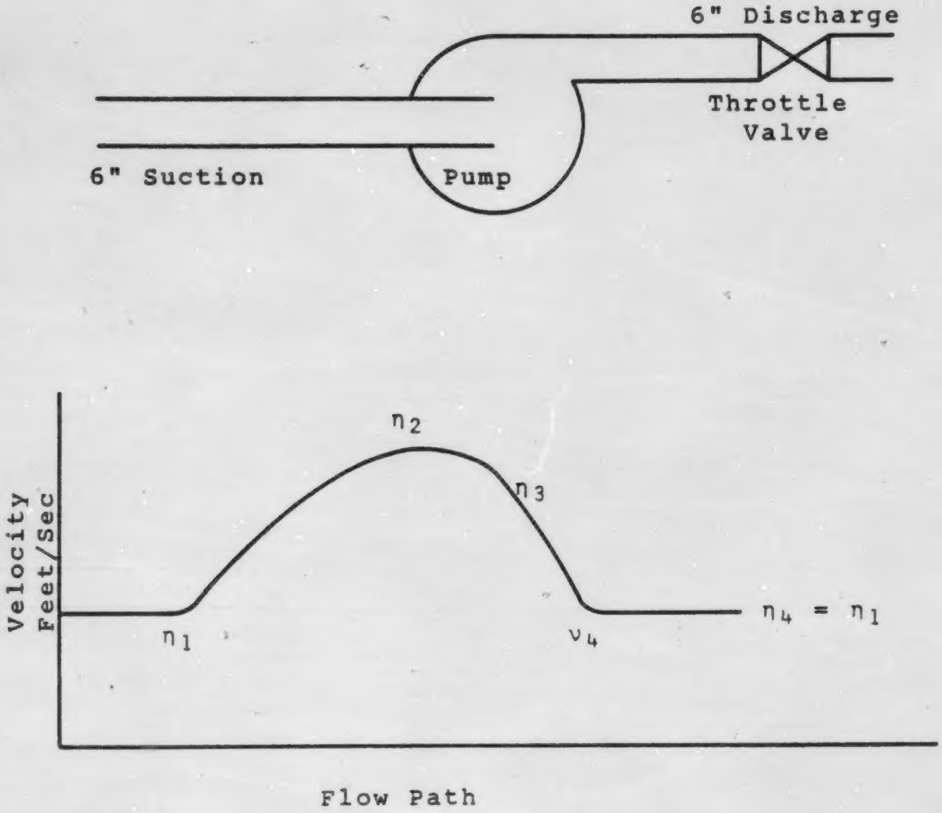

6" Discharge
Throttle Valve
6" Suction
Pump
η_2
η_3
Velocity Feet/Sec
η_1
ν_4
$\eta_4 = \eta_1$
Flow Path

Figure 30-2-1. Velocity through a Centrifugal Pump

As illustrated in Figure 30-2-1, the suction and discharge piping in this example are of equal size. With the pump running and the throttle valve open, it is logical that the fluid flow into the pump equals the fluid flow out of the pump. With equal pipe sizes, velocity η_1 equals velocity η_4. The point of highest velocity is at the outer tip of the impeller and is designated η_2. Velocity η_3 is somewhere in the volute. The decay of velocity from η_2 to η_4 is accompanied by a pressure rise proportional to the decrease in velocity squared.

Picture what happens when the throttle valve is shut with the pump still running. Velocities η_1 and η_4 go to zero but velocity η_2 theoretically exists. The impeller is imparting kinetic energy to the fluid but with the throttle valve closed, all of the kinetic energy is converted to pressure. This condition produces maximum discharge pressure. It is termed shutoff head.

As the throttle valve in Figure 30-2-1 is slowly opened, velocities η_1 and η_4 rise. This means that not all the kinetic energy added by the impeller is converted to pressure. Instead, some kinetic energy remains as the velocity head. It is logical that the pressure head is now less than the shutoff head.

The actual relationship between pump head and capacity is much more complicated. It should be recalled that pump head is comprized of pressure head, velocity head, and elevation head. Variables affecting pump head versus capacity include number of vanes in the impeller, thickness and curvature of the vanes, and volute design. The actual performance factors are so complicated that specific tests are conducted for each pump design to determine the performance characteristics for that design. The test results are plotted to yield an accurate performance chart such as the one illustrated in Figure 30-2-2.

Referring to Figure 30-2-2, pump head decreases as capacity increases. Efficiency increases to a maximum and then decreases as capacity increases. These relationships hold generally true for all designs of centrifugal pumps.

Pumps are designed to operate at the point of best efficiency. If the system design required 5000 gpm pump capacity at a pump head of 2800 feet, the pump represented by Figure 30-2-2 would be a suitable pump. This is because maximum efficiency for that pump occurs at about 5000 gpm and 2800 feet. However, if the system required a substantially different capacity or pump head, another pump design would be selected which would operate at best efficiency at the designated capacity and pump head.

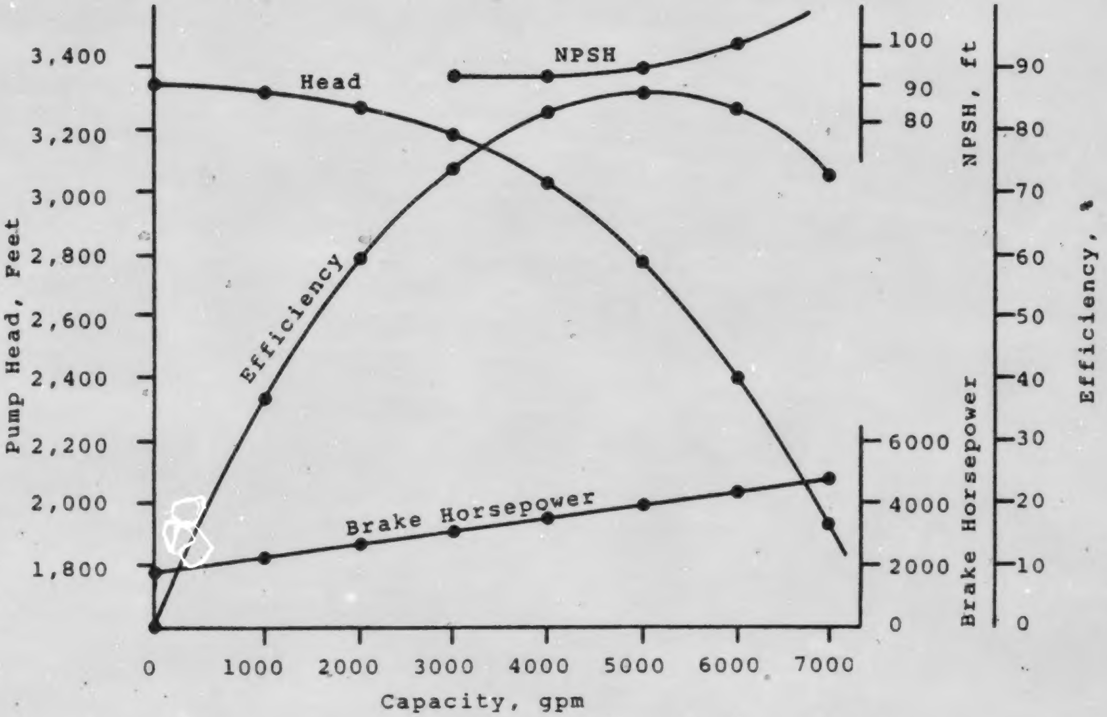


Figure 30-2-2. Example Performance Curves for Multi-Stage Centrifugal Pump

Net Positive Suction Head

Net Positive Suction Head (NPSH) is a term referring to the absolute pressure of the fluid at the lowest point of pressure in an operating pump. In a centrifugal pump, the point of lowest pressure is normally near the outer tip of the impeller vanes. At such a point, too low an absolute pressure permits portions of the fluid to vaporize and form gas bubbles. These bubbles collapse as they are forced into a larger pressure area. Such formation and collapse of bubbles is termed cavitation.

Cavitation in centrifugal pumps gives serious problems and is avoided. Cavitation causes reduced capacity, accelerated errosion of impeller vanes, and increased pump vibration.

The actual pressure at which cavitation occurs is dependent on several factors including pump design and the vapor pressure of the fluid. The minimum pressure necessary to prevent cavitation is designated by the pump manufacturer as required net positive suction head (RNPSH). The actual dynamic suction head provided in the operating system is the available net positive suction head (ANPSH). Cavitation does not occur as long as ANPSH is equal to or greater than RNPSH.

RECIPROCATING PUMP CHARACTERISTICS

Definitions

Principle terms associated with characteristics of positive displacement reciprocating pumps are capacity, displacement, pressure, brake horsepower, slip and speed. Definitions of these terms are:

- Capacity - The total volume of fluid delivered per unit time. Capacity is expressed in units of gallons per minute (gpm) and symbolized by Q.
- Displacement - The calculated capacity of the pump in gpm and symbolized by D.
- Pressure - The differential pressure from discharge to suction. It is noted that because discharge pressure is typically so much larger than suction pressure in systems using reciprocating pumps that discharge pressure alone is typically of concern. Pressure is symbolized by P.
- Brake horsepower - The horsepower delivered by the prime mover to the pump crankshaft. It is symbolized by bhp.
- Slip - The capacity loss as a percentage of suction capacity. Slip is expressed as a percentage and is

symbolized by S.

- Speed - The revolutions of the crankshaft per unit time speed is expressed in revolutions per minute (rpm) and symbolized by n.

Capacity Versus Head

Capacity of a reciprocating positive displacement pump is a function of speed, number of pistons, piston size, and stroke length. Theoretically, capacity equals displacement but in reality slip occurs such that capacity is less than displacement. Capacity is calculated by the formula:

$$Q = D(1-S) \qquad \text{Formula 30-2-1}$$

where

Q = Capacity in gpm

D = Displacement in gpm

S = Slip expressed as a decimal fraction (expressed as per unit)

Slip occurs from three sources: fluid compressibility, leakage past the piston, and reverse fluid flow through valves when valves are closing or seated. Fluid compressibility is of little consequence when pumping liquids except at very high discharge pressures. Leakage past pistons is normally very low. The largest component of slip by far is the reverse flow through valves. Slip values may range from 5 to over 30% dependent upon the fluid pumped, viscosity of the fluid, speed of the pump, and other variables.

Pump displacement is the calculated capacity of its pump assuming no slip. For single-acting reciprocating pumps, displacement is calculated by the formula:

$$D = \frac{A \times m \times n \times s}{231} \qquad \text{Formula 30-2-2}$$

where:

D = Displacement in gpm

A = Cross-sectional area of piston in square inches

m = Number of pistons

n = Speed of pump in rpm

s = Stroke of pump in inches

For double-acting reciprocating pumps, displacement is calculated by the formula:

$$D = \frac{(2A-a)m \times n \times s}{231} \qquad \text{Formula 30-2-3}$$

where:

D = Displacement in gpm

A = Piston cross-sectional area in in^2

a - Piston rod cross-sectional area in in^2

m = Number of pistons

n = Speed in rpm

s = Stroke in inches

For purposes of describing the interrelationship between capacity and pump head, the illustration of Figure 30-2-3 is used.

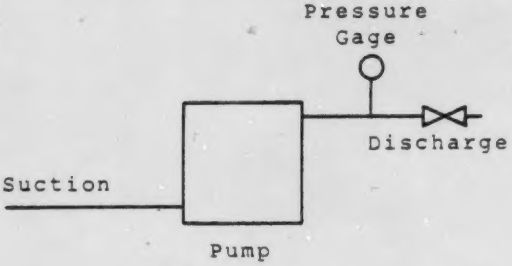


Figure 30-2-3. Simplified Sketch of Reciprocating Pump

Referring to Figure 30-2-3, let us assume that the pump is running at constant speed, the discharge valve is fully open, and the fluid is discharging to the atmosphere. With these conditions, the pressure gage reads zero if friction is disregarded. The capacity is probably about 90% or more of displacement because slip is least when discharge pressure is lowest. Now picture what happens as the discharge valve is closed. At some point of closing, the valve permits discharge flow exactly equal to pump capacity. If valve closure is increased slightly beyond this point, discharge flow tends to become less than suction flow. Nonetheless, its pump is moving essentially the same volume of fluid with each revolution. The result is a rapid increase in discharge pressure until the increased pressure causes flow through the valve equal to pump capacity. At such a valve setting pressure stabilizes at some value and discharge flow equals suction flow. Further closure of the valve results in another increase in pressure until discharge flow equals pump capacity. If its discharge valve is fully closed, pressure theoretically increases to infinity. In reality, some point in the system would rupture if the valve were closed with the pump running. To avoid this, safety relief valves are provided either integral with the pump or in the discharge piping before the first isolation valve.

In the foregoing discussion, slip was ignored. In reality, slip increases somewhat as discharge pressure increases. However, such increased slip is minimal and the rapid rise in discharge pressure with closing of the discharge valve always occurs. Therefore, it is concluded that with constant speed, capacity of the reciprocating pump is fixed by the pump design and that discharge pressure is equal to the pressure of the system receiving the discharge.

Effect of Speed

Speed of a reciprocating pump directly affects displacement and slip. As speed increases, displacement increases proportionately as indicated by Formula 30-2-3. Slip also increases as pump speed increases. Therefore, the increase in capacity is somewhat less than the increase in displacement by an amount determined by the increase in slip. The specific relationship is determined by tests conducted by the pump manufacturer and provide performance curves for the pump.

Net Positive Suction Head

The required net positive suction head (RNPSH) for reciprocating pumps is that head necessary to maintain fluid in contact with the piston during the intake stroke. The valve of RNPSH is dependent on piston size, pump speed, pump capacity, and pressure.

A large component of RNPSH is the acceleration head. Fluid flow in the suction line is constantly accelerating and decelerating with intake and discharge strokes of the pump. The head necessary to support the acceleration of fluid in the suction line is the acceleration head. It is calculated by the formula:

$$H_a = \frac{L \times V \times n \times c}{g \times k} \qquad \text{Formula 30-2-4}$$

where:

H_a = Acceleration head in feet

L = Length of suction pipe in feet

V = Mean velocity in the suction pipe in feet per second.

$$V = \frac{\text{gpm} \times .321}{\text{area of pipe, in}^2}$$

n = Speed of the pump in rpm

C = Function of the number of pistons

Duplex = 0.115

Triplex = 0.06

Quadraplex = .08

Quintuplex = .04

Sextuplex = .055

Septuplex = .028

g = Acceleration of gravity, 32.2 ft/sec^2

K = Factors for various fluids

Water = 1.4

Oil = 2.5

FUNCTIONAL TESTS OF PUMPS

Purpose

Functional testing of pumps serve two primary purposes. First, tests of the pump as an individual component demonstrate that the pump itself functions as designed. Secondly, tests of systems which use the pump demonstrate that the system functions as designed. The Nuclear Regulatory Commission requires that both individual pump tests and system tests be conducted after completion of installation whenever the system serves a safety related function. The owner also tests pumps in non-safety related systems to verify readiness to commence plant operations.

Systems Using Pumps

Most all piping systems in a nuclear power plant use pumps. Typical systems which use pumps in pressurized water reactors are listed in Table 30-2-1. Typical systems which use pumps in boiling water reactors are listed in Table 30-2-2.

Pump name	Number per plant	Flow, gpm	Head, ft	Design pressure, lb/in²		Driver, hp		Speed (nominal), rpm	Notes
Reactor coolant	4	93,000	305	2,500		8,000		1,200	
Component cooling water	2	4,800	250	250		500		1,800	
Residual heat removal.	2	3,000	270	600		400		1,800	
Containment spray	2	2,600	450	300		400		1,800	
Spent-fuel pit	2	2,300	125	250		100		1,800	
Charging (centrifugal)	2	650	3,000	2,800		900		4,850	Gear drive
Safety injection	2	425	2,500	2,500		400		3,600	
Chilled water	2	400	150	150		40		3,600	
Spent-resin sluicing	1	140	250	150		25		3,600	Canned
Spent-fuel pit skimmer	2	100	50	150		5		3,600	
Reactor-coolant drain tank	2	100	300	150		20		3,600	Canned
Charging (positive displacement)	1	98	5.800	3,200		200		50/250	Variable speed
Boric acid transfer	4	75	235	150		15		3,600	Canned
Floor drain tank	1	35	250	150		15		3,600	
Recycle evaporator feed	2	30	320	150		20		3,600	Canned
Boron injection recirculation	2	20	100	150		3		3,600	Canned

Table 30-2-1.

Typical Pumps in Pressurized Water Reactor

Pump name	Number per plant	Flow, gpm	Head, ft	Design pressure, lb/in^2		Driver, hp			Speed (nominal), rpm	Notes
Recirculating coolant	2	35,400	865	1,675		7,200			1,800	
RHR service water	4	7,300	115	150		300			900	
Residual heat removal	3	7,100	275	450		900			1,800	
High-pressure core spray	1	6,110	900	1,600		3,000			1,800	
Low-pressure core spray	1	6,110	730	550		1,750			1,800	
Closed cooling water	3	1,700	110	250		60			1,800	
Reactor-core isolation cooling	1	725	2,800	1,500		800			4,000	Turbine-driven-variable speed
Fuel-pool cooling	2	600	300	150		75			1,800	
Reactor-water cleanup	2	150	500	1,400		50			3,600	
Control rod drive hydraulic system	2	95	3,500	1,750		300			1,800	
Standby liquid control	2	40	2,800	1,400		40			1,800	Reciprocating pumps

Table 30-2-2.

Typical Pumps in Boiling Water Reactor

Functional Design Features

The decision on what tests will be conducted is based on "what are the functional design features?" If all functions of the pump and system are known, it is relatively easy to establish a series of tests which will determine that such functions are served by the pump and system. The key for assuring that all necessary tests will be conducted is whether a test objective exists for each functional design feature. If there is a match between test objectives and all functional design features, adequate test plans have been developed.

Plant Operational Status

Functional testing is performed during the time interval between installation and power operation. These tests are subdivided into four categories: preoperational tests, cold functional tests, hot functional tests, and start-up tests. Assignment of specific tests of pumps to any of these categories involves engineering judgment to some extent and, consequently, absolute categorizations of pump tests is not attempted herein. The purpose of each category of tests and example pump tests within each are as follows:

- Preoperational tests - These tests assure that components, partial systems, or systems operate in accordance with design criteria. These tests are performed after installation and prior to fuel load. They include hydrostatic testing and individual pump tests.
- Cold functional tests - These tests obtain operational data of equipment and verify system functional performance. These tests are performed after preoperational testing and prior to fuel load. They include certain individual pump tests and pump system tests.
- Hot functional tests - These tests apply only to pressurized water reactors and are performed prior to fuel load. They essentially repeat cold functional tests with the system at elevated temperature and pressure. These tests verify the functional performance of systems at operating and design temperatures and pressures.
- Startup tests - These tests are conducted after fuel load. They verify that reactor operation complies with design requirements under normal and transient operating conditions. Pump tests are not included per se. Instead, startup tests include the observation of the proper functioning of pumps under the various operational modes.

Individual Pump Tests

Individual pump tests verify that pump functional design features are met. Certain individual pump tests are performed by the pump manufacturer. Such tests are not repeated at the installation site except as necessary to confirm that the pump properly functions as installed.

Typical tests of individual pumps after installation include:

- Direction of rotation
- Vibration
- Motor load versus time
- Seal leakage
- Seal cooling
- Flow and pressure characteristics
- Acceleration and coastdown.

Direction of Rotation Tests

Centrifugal pumps will function if direction of rotation is incorrect but at a less capacity and with risk of damage. If rotation of a gear pump is reversed, the fluid is pumped backwards, i.e., from discharge to suction. Oftentimes, the reciprocating and rotary pumps have gear boxes between the prime mover and the pump which will operate only in one direction. Attempts ar reverse direction has high potential for damaging the gears. Therefore, it is important that the installation of the prime mover result in correct rotation of the pump.

Direction of rotation tests are performed with the prime mover disconnected from the pump shaft. In this manner, damage should not result in the event direction of rotation is incorrect. Power is momentarily applied to the prime mover and the direction of rotation of its drive shaft is visually observed. The observed direction of rotation is compared with the required direction of rotation as specified in the pump specification or installation drawing. Incorrect rotation indicates improper power connections to the prime mover.

Vibration Tests

Pump manufacturers typically balance the shafts of the pump and prime mover prior to shipment. However, installation mounts and couplings may be off line or of sufficient flexure to permit excessive vibration. Also, fluid flow with the pump running may induce vibrations in the suction or discharge piping. Cavitation is typically audibly heard before it has much effect on vibrations. Gross cavitation causes noticeable vibration. Therefore, the vibration test primarily determines the adequacy of alignment mounts, and pipe hangers at installation with respect to preventing vibration.

Vibration tests involve running the pump with fluid flow and observing vibration. In most cases, visual and touch observation of vibration is sufficient because the acceptance criteria typically requires smooth, normal running for the given type of pump. Accelerometers attached to the pump provide for a much more sensive vibration test. Some utilities use accelerometers for testing critical pumps in order to determine when corrective maintenance is necessary. In such cases, the initial test after installation serves as a "base line" against which all subsequent tests are compared.

Excessive vibration detected or initial testing typically indicates a problem with the installation rather than the pump itself. Sources of vibration include misalignment between prime mover and pump, "soft" mounts, and too few hangers to stiffly support the suction or discharge piping. However, cavitation may also be the culprit.

Motor Load Versus Time Tests

Motor load versus time tests verify the ability of the motor to satisfactorily operate the pump for sustained time periods. Typically, the motors of motor driven pumps are designed for continuous duty at rated pump capacity or higher without exceeding power and temperature limits.

This capability is tested by the motor load versus time test.

This test is performed by running the motor driven pump at the pump's rated capacity and head for a specified time such as one or two hours. Current to the motor is monitored to verify that current drawn under full load conditions does not exceed limits. Stator and bearing temperatures are monitored to confirm that these temperatures do not exceed limits under full load conditions. Also, this test may include measurement of starting currents with the aid of chart recorders connected to ammeters.

Seal Leakage Tests

Pump shaft seals are either mechanical seals or compressible packing seals. Both types of seals require small amounts of leakage for cooling. Leakage along the pump shaft, a percentage of pump discharge, or a separate water supply provides seal cooling. In all three types, leakage occurs to the atmospheric side of the seal. The amount of leakage is indicative of the condition of mechanical seals and the proper compression of compressible seals.

Seal leakage tests are conducted with the pump running at normal head and with seal cooling water supplied. The leakage is collected for a timed interval in a graduated container. The volume collected divided by the time of collection equals the leak rate. Excessive leakage is indicative of poor seals while insufficient leakage is indicative of excess sealing which may lead to overheating.

Seal Coding Tests

Seal coding tests confirm that seal temperatures are maintained within specified limits with the pump operating at full load and with the normal cooling system in service. While this test may be stipulated by engineering for any pump, it applies mainly to pumps having a separate supply of seal cooling water. Normally, engineering specifies acceptance criteria for this test in terms of temperature rise of the cooling water. With a known flow of cooling water, the temperature rise of the water is directly dependent on the temperature of the seal. Engineering calculates the maximum temperature rise which is expected if the seal were at its temperature limit. As long as actual temperature rise remains below the maximum calculated value, the seal temperature must be below its limit.

Another method of specifying limits involves calculation of temperature at the surface of the seal housing. Engineering calculates the surface temperature which occurs if the seal temperature is at its limit. As long as actual seal housing temperature is below the calculated value, seal temperature is also below its limit.

Seal cooling tests using the temperature rise limits measure the inlet and outlet temperatures of the cooling water. The difference between these temperatures in compared with the limit. Tests using seal housing temperature limits, measure housing temperature with a contact temperature measuring device, e.g., contact thermometer or thermocouple. The measured value is compared directly with the limit.

Flow and Pressure Characteristics Tests

These tests verify that the pump functions as designed when the pump is operated in the system containing the pump. The specific test used is dependent on the type of pump being tested.

Tests of centrifugal pumps require measurement of discharge pressure and discharge flow. A typical test configuration is illustrated in Figure 30-2-5. Actual connection points for the pressure gage and flow meters must be in a length of straight pipe sufficiently downstream of elbows to permit sensing laminar flow. Sometimes, flow straightening vanes are necessary to provide for laminar flow at the sensors.

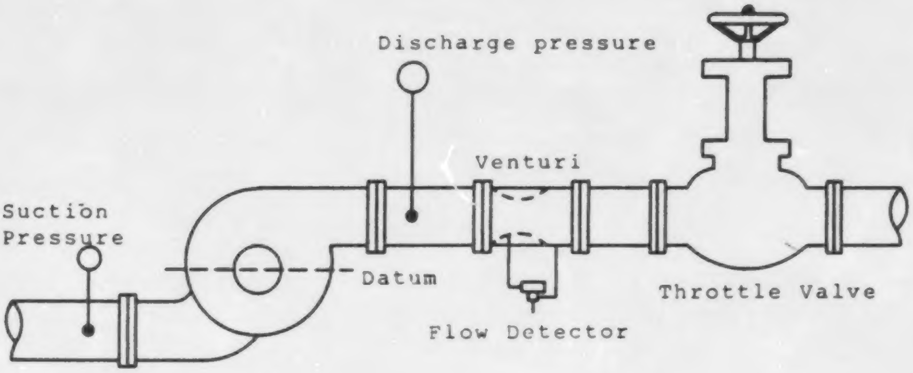


Figure 30-2-5. Example Pressure and Flow Testing

Pump head of centrifugal pumps equals the algebraic difference between total discharge head and total suction head. Pump head is therefore expressed by the formula:

$$H = H_d - H_s \qquad \text{Formula 30-2-5}$$

where:

H = Pump head in feet
H_d = Total discharge head
H_s = Total suction head

Total discharge and total suction heads are comprized of pressure head, velocity head, and elevation head. Pressure head is determined by converting measured pressure in lb/in^2 to feet by formula 30-2-5. As described later, pressure gage readings sometimes require correction to account for that vertical distance from the datum.

$$H_p = P \times \frac{144}{w}$$ Formula 30-2-6.

where:

H_p = Pressure head in feet
P = Gage pressure in lb/in^2
w = Specific weight of fluid in lb/ft^3

Velocity head is determined from flow measurements. Because most flow measuring systems indicate flow in units of gallons per minute (gpm) or cubic feet per second (ft^3/sec), conversion to feet per second is necessary to obtain velocity units. Flow in gpm multiplied by 2.228×10^{-3} equals flow in ft^3/sec. Flow in ft^3/sec divided by the cross-sectional area of the pipe in ft^2 equals velocity in ft/sec. Once velocity in ft/sec is known, velocity head is calculated by:

$$H_v = \frac{V^2}{2g}$$ Formula 30-2-7.

where:

H_v = Velocity head in feet

V^2 = Velocity of fluid in ft/sec
g - Gravitational acceleration, 32.174 ft/sec^2

Elevation head of a fluid is the vertical distance in feet above or below a reference datum. With the pump centerline as the datum, the discharge elevation head is the vertical distance from the datum to the highest point in the discharge system. The pump must add energy to the fluid to raise it to such level. The suction elevation head is the vertical distance from the level of supply fluid to the datum. In a closed loop system, it is the vertical distance from the lowest point in the system to the datum. Suction elevation is positive when the supply level is above the datum and negative when it is below the datum.

An elevation head also exists with respect to the suction and discharge pressure gages whenever the gages are at an elevation different from the datum. In such cases the pressure indicated by the gage is corrected prior to calculating pressure head. The vertical distance between the pressure gage and the datum is measured in feet. This value is divided by 2.307 to obtain the gage elevation head in lb/in^2. The value of lb/in^2 is subtracted from gage reading when the gage is below the datum and added to gage reading when the gage is above the datum.

Adding the values of pressure head, velocity head, and elevation head yields total head of either suction or discharge. Substituting terms for these heads for H_d and H_s in formula 30-2-5 yields:

$$H = \left(\frac{Pd \times 144}{w} + \frac{Vd^2}{2g} + Z_d\right) - \left(\frac{P_s \times 144}{w} + \frac{V_s^2}{2g} + Z_s\right)$$

where: Formula 30-2-8

H = pump head, ft

$\frac{Pd \times 144}{w}$ = discharge pressure head (corrected for gage elevation)

$\frac{Vd^2}{2g}$ = discharge velocity head

Zd = discharge elevation head

$\frac{Ps \times 144}{w}$ = suction pressure head (corrected for gage elevation)

$\frac{Vs^2}{2g}$ = suction velocity head

Z_s = suction elevation head

Examination of formula 30-2-8 reveals that if discharge velocity equals suction velocity, the velocity heads subtract to zero. The discharge flow of centrifugal pumps is so much larger than seal leakage flow that it can be assumed that discharge flow equals suction flow. If discharge and suction piping is of the same internal cross-sectional area, it follows that discharge velocity equals suction velocity. Therefore, the velocity head becomes important when different pipe sizes exist between suction and discharge.

Referring to Figure 30-2-5, various combinations of discharge pressure and flow are obtained by various settings of the discharge throttle valve. Tests of constant speed centrifugal pump involve determination of pump head at various capacities and comparing the results with the pump performance curves furnished by its pump manufacturer. For variable speed centrifugal pumps, the throttle valve is left fully open and the speed of the pump is varied. Total head and flow at various speeds is compared with the supplier's pump performance curves.

Tests of jet pumps verify either flow or suction pressure dependent on the function of the pump. For jet pumps used as evacuators, the absolute pressure of the evacuated space is measured and compared with specified values. For jet pumps used as eductors to provide a desired flow rate, the discharge flow rate is measured and compared with specified values.

Tests of positive displacement pumps verify capacity at design discharge pressure. Flow meters installed in the discharge line may be used or volume pumped in a timed interval , may be measured. In the latter method, the volume pumped may be measured on the discharge side or the suction side. For measurement on the discharge side, a hose is connected downstream of the pump and between two valves. The valve farthest downstream is closed such that the entire pump discharge goes into the hose. The upstream valve is throttled to obtain discharge pressure equal to design pressure. At that throttle setting, the pump discharge is collected in a drum for a timed interval. The amount collected divided by the collection time equals pump capacity. Some positive displacement pump systems have a supply reservoir which permits calculating capacity. The hose connection and throttle valve is established as before. The amount by which the supply reservoir decreases during the timed pumping interval is used to calculate capacity.

Acceleration and Coastdown

Electrical motors, which serve as centrifugal pump prime movers, must develop sufficient torque to bring the pump up to operating speed within a designated time frame. The current drawn by the motor peaks at the instant power is applied and decays to normal operating current when the speed reaches operating speed. If too much time elapses, the excess current can damage the motor windings and insulation. Engineering calculates time for acceleration by formula 30-2-9.

$$t = \frac{wk^2 \times \Delta rpm}{308T} \qquad \text{Formula 30-2-9}$$

where:

t = time, sec

wk^2 = total moment of inertia, lb-ft^2

T = torque, lb - ft

Acceleration tests of centrifugal pumps measure the time from initial start to full operating speed. One method of measurement uses chart recorders for plotting current versus time. Another method clocks the time for speed to reach operational speed using a stop watch and a tachometer. The first method is typically more accurate.

Acceleration tests serve two primary purposes. First, the test verifies that the motor is capable of starting the pump under system operating conditions without damage to the motor. Second, the test verifies that safety related systems, which are normally idle, will function as intended when power is applied to the motor for any reason.

Coastdown tests are performed on those systems which normally have flow and whose flow decay is important to reactor safety. For example, the reactor coolant system must be operating in order to operate the reactor. If power is lost to reactor coolant pumps, safety feature actuation systems shut down the reactor. Should this occur, the coastdown flow of reactor coolant provides cooling which is additional to other safety cooling systems.

Coastdown tests are performed by measuring flow decay from time of interrupting power to the pumps to time of zero flow. Chart recorders are connected to the flow indication circuitry to plot flow versus time. A signal from an auxilliary contact on the pump switchgear can be patched to the chart recorder to give indication of the time of opening the switchgear. A backup measurement may be obtained from either pump head or pump speed. Decay of head or speed can be used for calculating flow decay or comparing the data with special pump performance curves which have been established for this purpose.

Coastdown tests serve the purpose of providing actual data for engineering's use in calculating reactor safety margins under postulated accident conditions.

System Tests

System tests verify that system functional design features are met. With respect to pumps, system pressure and flow requirements are typically tested in conjunction with individual pump tests. That is, the individual pump capacity and head features are typically tested with the entire system. Other requirements for pumps which involve separate system testing pertain to automatic controls of the pump's operation.

Automatic controls associated with pump operation are typically of two varieties. One is a stop-start function and the other is a variable flow function.

Stop-Start System Tests

Certain pumping systems, such as core spray, containment spray, and waste collecting systems, are normally idle. Such systems are automatically started upon a control system demand. For example, containment pressure and temperature might be sensed and if either exceeds limits, a command is given to automatically start the containment spray pumps. In all such systems, instrumentation and control (I & C) components and circuitry are used to (1) sense the parameters of concern, (2) compare measured values against set points, and (3) initiate either start or stop signals to the pumps being controlled by that I & C system whenever measured values exceed set points. A simplified block diagram illustrating an automatic start-stop control system is provided by Figure 30-2-6.

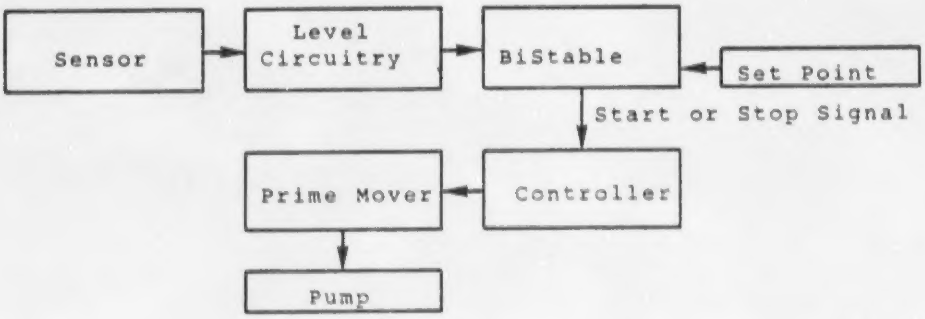


Figure 30-2-6. Block Diagram of Start-Stop Control Function

Tests of start-stop control systems verify that the pump starts or stops at the specified set point for each parameter of concern. Dependent upon the specific systems, one or more parameters may actuate the pump either as individual parameters or as the collective values of the parameters. The systems test simulates each parameter and determines if the pump starts or stops at each designated set point or combination of set points. Such tests require connection of hoses from pump discharge to a collection tank whenever it is undesirable to operate the fluid system. For example, testing of containment spray pumps would collect pump discharge because equipment within containment could be damaged by the spray.

Variable Flow System Tests

A few pumping systems are continuously operating but at various values of flow. For example, main feed water pumps are typically variable speed centrifugal pumps whose speed at any time is dependent on parameters such as steam generator water level. In this case, changes in water level result in a signal to the throttle valve controls of the feed pump turbine which adjusts turbine speed as necessary. Variable speed control systems (1) monitor designated parameters, (2) measure the value of the parameters, and (3) provide a continuous signal which is proportional to the value of the designated parameter. The continuous signal regulator pump speed either directly or inversely proportional to the values of the parameters. The simplified block diagram in Figure 30-2-7 illustrates a variable speed control function.

Tests of variable speed pumps simulate various levels of the designated parameters and determines if pump speed is properly regulated by the control systems. Pump speed may be indicated by flow or by revolutions per minute.

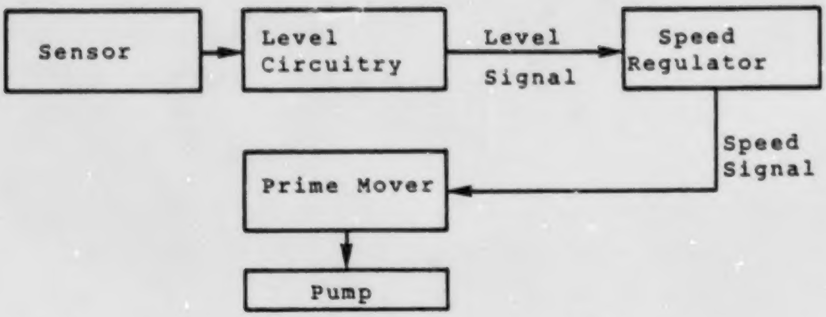

Sensor
Level Circuitry
Level Signal
Speed Regulator
Speed Signal
Prime Mover
Pump

Figure 30-2-7. Block Diagram of Variable Speed Control Function

Pump speed at various values of designated parameters is recorded and compared with either a curve or table which provides design values. Level circuitry and the speed regulator are adjusted as necessary to obtain pump speed variations with parameter changes which match the design values within specified limits.

FUNCTIONAL TEST PROCEDURES

General Description

A test procedure is prepared and approved for use for each functional test to be performed. Each test procedure is sufficiently detailed for a qualified individual to perform the test without direct supervision. In addition, the procedure identifies witness and hold points where the Quality Control Department has elected to witness portions of the test or inspect designated test conditions. Test procedures receive independent review and approval prior to use and they provide for the recording of test data on the procedure. The completed procedure serves as the record of the test and provides test data for analysis and evaluation to determine acceptability of test results.

Format

The exact format of a test procedure varies somewhat from plant to plant. Nonetheless, all have in common seven sections. These are (1) title, number and revision, (2) test objectives, (3) test equipment, (4) limitations, (5) prerequisites, (6) procedure, notes and cautions, and (7) acceptance criteria.

- Title, number, and revision - The title names the test and the component or system to be tested. The number is typically an arbitrary number assigned by the owner. Each test procedure is given a unique number to permit easy reference to the procedure. The revision level is indicated by ascending numerical numbers or alpha designators or by date of approval. An example of title, number and revision is "Reactor Coolant Flow Test Procedure, TP0200.11.2" where TP = test procedure, 0200.11 = assigned number and .2 = revision 2.

- Test objectives - Test objectives are stated in terms of the functional design features which will be tested by the procedure. A given procedure may test any number of functional design features provided the test is manageable within the necessary prerequisites.
- Test equipment - Test procedures require the use of installed measuring and test equipment as much as possible. When additional measuring and test equipment is needed, the procedure lists the specific typd of equipment which will be necessary. Examples include ammeters, voltmeters, tachometers, chart recorders, and special fluid collection containers.
- Limitations - This section of the procedure lists limitations if any, which apply to the conduct of the entire test. Examples include the minimum temperature at which the test can be performed, temperature ranges to be observed at all times during the test, and prohibitions on simultaneously starting pumps from a common power source.
- Prerequisites - This section lists all the conditions which must be established prior to commencing the test. Examples include filling and venting of the system, availability of pumping power, operability of pumping power, operability of instrumentation and control systems, safety tagging of switches and valves which must not be operated except as required by the test procedure, and isolation of interconnections which are not to be tested by the procedure.
- Procedure, notes, and cautions - This section provides sequential, step-by-step instructions for conducting the tests. The first step is typically to verify that each prerequisite and limitation has been

satisfied. Succeeding steps provide sequential action for conducting the test, recording test results, and returning the system to a described condition. Notes may be added, as necessary, to provide information which assists the tester. For example: "Note: the flow readout in lb/hr must be converted to gpm". Cautions are added, as necessary, to alert the tester to adverse conditions which could occur if the component or system malfunctions. For example: "Caution: The next step starts the containment spray pump. If unusual noise or vibration is observed, immediately stop the pump and notify the test supervisor". It is good practice to place notes and cautions immediately prior to the procedural step to which they apply. In this manner, the tester is more likely to observe the note or caution prior to performing the step.

- Acceptance criteria - This portion of the procedure lists the specific functional behavior which should be exhibited by the pump or system as determined from design specifications. The actual test results are evaluated and compared with acceptance criteria to determine if the pump or system can be declared acceptable for reactor plant operation.

Test Data Analysis and Evaluation

Test data may require engineering analysis to determine the significance of the data in terms of functional design features. Such analysis and evaluation of test data is performed by the responsible engineering group to determine acceptability of the pump or system. The results of the data analysis and evaluation are recorded on the test procedure.

Records

The test procedure serves as the record. The tester signs each procedural step as it is completed and records test data at steps requiring data collection. The engineer who evaluates the test data signs each acceptance criterion as it is confirmed that the test data provides satisfactory evidence of meeting acceptance criteria. The test supervisor also typically signs the completed procedure to certify that the procedure has been followed and that test results are complete and accurate to the best of the supervisor's knowledge.

EXERCISES

The following exercises serve to reinforce the information presented in this module. Answer each of the following exercises and check your answers using the answer key provided following each set of exercises.

A. This set of exercises refers to the information on Centrifugal Pump Characteristics and Reciprocating Pump Characteristics.

1. Define the following characteristics of centrifugal pumps:
    a. pump capacity

    b. pump head

    c. output power

    d. brake horsepower

    e. pump efficiency

2. As the discharge valve is closed in a centrifugal pump system, head (increases, decreases) and capacity (increases, decreases).
3. Describe how cavitation is avoided in a centrifugal pump.

4. Which organization provides performance curves for centrifugal pumps.

5. Define the following characteristics of reciprocating positive displacement pump:
    a. capacity

   b. displacement

   c. slip

6. Describe the relationship between capacity and discharge pressure for a positive displacement pump operating at a constant speed.

7. Why should the discharge path of a reciprocating positive displacement pump not be closed if the pump is running?

Check your answers to these exercises on Centrifugal Pump Characteristics and Reciprocating Pump Characteristics:

1. a. Capacity is the volume of fluid per unit time delivered by the pump.
   b. Head is the net work done on a unit weight of fluid in passing from the suction to the discharge.
   c. Output power is the liquid horsepower delivered by the pump to the fluid.
   d. Brake horsepower is the horsepower delivered by the prime mover to the pump shaft.
   e. Efficiency is the ratio of output power to brake horsepower.
2. Head increases, capacity decreases.
3. Cavitation is avoided by maintaining a dynamic suction head greater than the required Net Positive Suction Head identified by the pump manufacturer.
4. The pump manufacturer.

5. a. Capacity is the volume of fluid delivered per unit time.
   b. Displacement is the calculated capacity.
   c. Slip is the capacity loss as a percentage of suction capacity.
6. Capacity is essentially constant regardless of discharge pressure because capacity is fixed by pump design. Discharge pressure equals that of the system receiving the discharge.
7. Closing the discharge path of an operating positive displacement pump results in a rapid rise in discharge pressure which may rupture the pump or discharge piping.

B. This set of exercises refers to the information on the Functional Tests of Pumps.

1. State two purposes of pump functional tests.

2. State the purpose of the following individual pump tests:
    a. direction of rotation

    b. vibration

    c. motor load versus time

    d. seal cooling

    e. flow and pressure characterisitcs

    f. start-stop system tests

    g. variable flow system tests

3. Briefly describe how the following tests are conducted.
    a. direction of rotation

    b. seal cooling

    c. acceleration tests

d. start-stop system tests

4. Given the following values measured in a water transfer system, calculate pump head:

    Discharge measurements: $P = 60\ \text{lb/in}^2$, Flow = 500 gpm, pressure gage elevation = 26 ft, pipe cross-sectional area = $.181\ \text{ft}^2$, highest elevation = 52 ft.

    Suction measurements: $P = 10\ \text{lb/in}^2$, pressure gage elevation equals 8 ft, pipe cross-sectional area = $.181\ \text{ft}^2$, water supply level = 22 ft.

    Other Data: pump datum = 12 ft, specific weight of water = $62.2\ \text{lb/ft}^3$.

Check your answers to the exercises on the Functional Tests of Pumps:

1. Pump functional tests verify that (a) the pump functions are designed and (b) the system containing the pump functions as designed.
2. a. Direction of rotation tests verify that the installed prime mover rotates in the direction that the pump must operate.
    b. Vibration tests verify that the pump operates under load without excessive vibration.
    c. Motor load versus time tests verify that the pump motor operates continuously under load without overheating or drawing excessive current.
    d. Seal cooling tests verify that with the pump operating under load and normal cooling provided the seal temperature limit is not exceeded.

- e. Flow and pressure characteristics tests verify that pump performance in the system is consistent with performance curves provided by the manufacturer.
- f. Start-stop system tests verify that the pump starts or stops at designated set points for the controlling parameters.
- g. Variable flow system tests verify that pump flow varies with changes in controlling parameters as designed.

3.
- a. Direction of rotation tests are performed by disconnecting the motor to pump coupling, applying power to the motor and visually observing direction of rotation of motor shaft.
- b. Seal cooling tests are performed by verifying normal seal cooling flow, operating the pump at full load for a designated time, and measuring either rise in cooling water temperature or temperature of seal housing.
- c. Acceleration tests are performed by measuring the time from initial start of the pump until it is running at operating speed. Charting current, flow, or discharge pressure may be used for the measurement.
- d. Start-stop system tests are performed by simulating the control parameters, increasing the simulated signal level, and observing the level at which the start or stop function occurs. Individual parameters or combinations of parameters may be simulated.

4. 163.81 feet

Solution:

a. Suction and discharge velocity heads are equal and subtract to zero.

b. Correction for discharge pressure gage reading is $(26 \text{ ft} - 12 \text{ ft}) \div 2.307 = 6.07 \text{ lb/in}^2$.

c. Correction for suction pressure gage reading is $(8 \text{ ft} - 12 \text{ ft}) \div 2.307 = -1.73 \text{ lb/in}^2$.

d. $$H = \frac{Pd \times 144}{w} + Zd - \frac{Ps \times 144}{w} + Zs$$

$$= \frac{66.07 \times 144}{62.2} + 40 - \frac{8.27 \times 144}{62.2} + 10$$

$$= 192.96 - 29.15$$

$$= 163.81$$

C. Pump Testing

1. Visit a power plant in your area and observe the periodic test of a pump (or pumps) used in one of the power plant systems.

2. Prepare a report on your visit following the format outlined in the Procedures section of this module.

3. Collect the pump data and testing results as listed in data tables 30-2-3 and 30-2-4 respectively.

MATERIALS

Materials are not required for this module.

PROCEDURES

1. Make arrangements with a power plant in your area to observe a periodic test of a pump (or pumps) used in one of the plant systems as requested in exercises C.1, C.2 and C.3.

2. Visit the plant and observe the pump testing.

3. Complete the enclosed data tables. Table 30-2-3 is for the pump characteristics and Table 30-2-3 is for stating the purpose and description of each of the pump tests performed.

4. Prepare a short report on your visit which includes the following information:
   a. Data
   b. Plant visited
   c. Type of pump tested
   d. Type of system in which the pump is used
   e. Pump characterisitcs
   f. Types of tests
   g. Purpose of tests
   h. Descriptions of tests
   i. Results of tests

DATA TABLE

As requested in the Procedures section of this module collect the following data on the pumps tested:

Table 30-2-3

Pump Characteristics

Pump Name	
Rated Flow (gpm) Pump Head (ft) Design Pressure (psig) Driver Power (HP) Speed (nominal) (rpm) Remarks	

Table 30-2-4

Pump Tests, Purposes and Descriptions

Test	Purpose	Description
Direction or Rotation		
Vibration		
Motor Load vs. Time		

Table 30-2-4 (Continued)

Pump Tests, Purposes and Descriptions

Test	Purpose	Description
Seal Leakage		
Seal Cooling		
Flow and Pressure Characteristics		
Acceleration		
Coastdown		

REFERENCE MATERIALS

NRC, Regulatory Guide 1.68, Initial Test Programs for Water-Cooled Nuclear Power Plants, U.S. Nuclear Regulatory Commission, 1978

ASME, ANSI N45.2.8, Supplementary Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems for the Construction Phase of Nuclear Power Plants, American Society of Mechanical Engineers, 1975

NRC, Regulatory Guide 1.116, Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems, U.S Nuclear Regulatory Commission, 1977

ASME, ANSI N45.2, Quality Assurance Program Requirements (Design and Construction), American Society of Mechanical Engineers, 1972

EEE, 338, IEEE Standard Criteria for the Periodic Testing of Nuclear Power Generating Station Safety Systems, The Institute of Electrical and Electronic Engineers,1974

IEEE 334, IEEE Standard for Type Tests of Continuous Duty Class IE Motors for Nuclear Power Generating Station, The Institute of Electrical and Electronic Engineers, 1974

I.J. Karassih, W.C. Krutzsch, W.H. Fraser, J.P. Messina, Pump Handbook, McGraw-Hill, 1976

TEST

A. Answer the following set of questions as either true or false.

____ 1. Centrifugal pump performance curves furnished by the pump manufacturer plot head, efficiency, brake horsepower and net positive suction head against capacity. These curves are furnished for each pump design and identify how that design should perform.

____ 2. Centrifugal pump functional tests verify that a pump performs in its system as predicted by the pump performance curves.

____ 3. Pump head of the centrifugal pump is the algebraic difference between the total discharge head and the minimum required NPSH for the pump.

____ 4. The total discharge head consists of the sum of the pressure head, velocity head, elevation head and the turbulence head of the pump.

____ 5. Pump head represents the net work done on a unit weight of fluid in passing from the suction to the discharge.

____ 6. Reciprocating positive displacement pumps have an essential constant capacity when operating at constant speed regardless of discharge pressure.

____ 7. The discharge pressure of the positive displacement pump is proportional to the pump head provided that laminar flow is monitored through the pump.

____ 8. The capacity of variable speed reciprocating pumps varies directly proportional to the speed.

____ 9. Tests of reciprocating and rotary pumps verify that capacity at a designated speed and discharge pressure always be within ± 2% of its nameplate data.

____ 10. Cavitation in centrifugal pumps is the formation of gas bubbles on the impeller which is permitted by suction pressure lower than the vapor pressure of the fluid.

____ 11. Cavitation in reciprocating pumps is the formation of gas at the fluid-piston surface interface.

____ 12. Cavitation in any pump is prevented by providing a total discharge head greater than the required net positive suction head.

____ 13. Pump functional tests serve to verify that both the pump and the system containing the pump function as required by design intent.

____ 14. Most pump tests are performed during preoperational testing and cold functional testing. For PWRs, certain pump tests are repeated during not functional testing.

____ 15. Individual pump tests typically consist of (1) direction of rotation tests, (2) vibration tests, (3) motor load versus time tests, (4) seal leakage tests, (5) seal cooling tests, (6) flow and pressure characteristics tests, and (7) acceleration and coastdown tests.

____ 16. Pump system functional tests can be classified as stop-start functions, reverse-flow functions and motor winding overcurrent functions.

____ 17. Systems which have automatic starting or stopping of pumps are tested by simulating the control parameters and comparing the parameter level at which start or stop occurs with the designated set point. One or more parameters may activate the function either individually or in combination.

____ 18. Systems which have automatic adjustment of pump speed are tested by simulating the control parameters and measuring the change in flow. Change in pump head or speed could also be measured.

____ 19. Each functional test is performed in accordance with a test procedure. As a minimum, test procedures consist of seven sections: (1) title, number, and revision, (2) date, (3) temperature, (4) operator experience, (5) prerequisites, (6) test location and (7) acceptance criteria.

____ 20. The test procedure normally serves as the test record. Each procedural step is signed as it is completed, test results are recorded on the procedure, and verification signatures confirm that acceptance criteria are met.

B. Answer the following questions as indicated.

1. Define the terms capacity, pump head, output power, brake horsepower, and pump efficiency as they relate to centrifugal pumps.

2. Define the terms capacity, displacement, and slip as they relate to reciprocating pumps.

3. Recognize typical performance curves for centrifugal pumps and relate pump operating conditions to the curves.

4. Define cavitation and describe how it is avoided.

5. Describe the interrelationships of capacity, discharge pressure, pump speed, and discharge throttle valve settings for a reciprocating positive displacement pump.

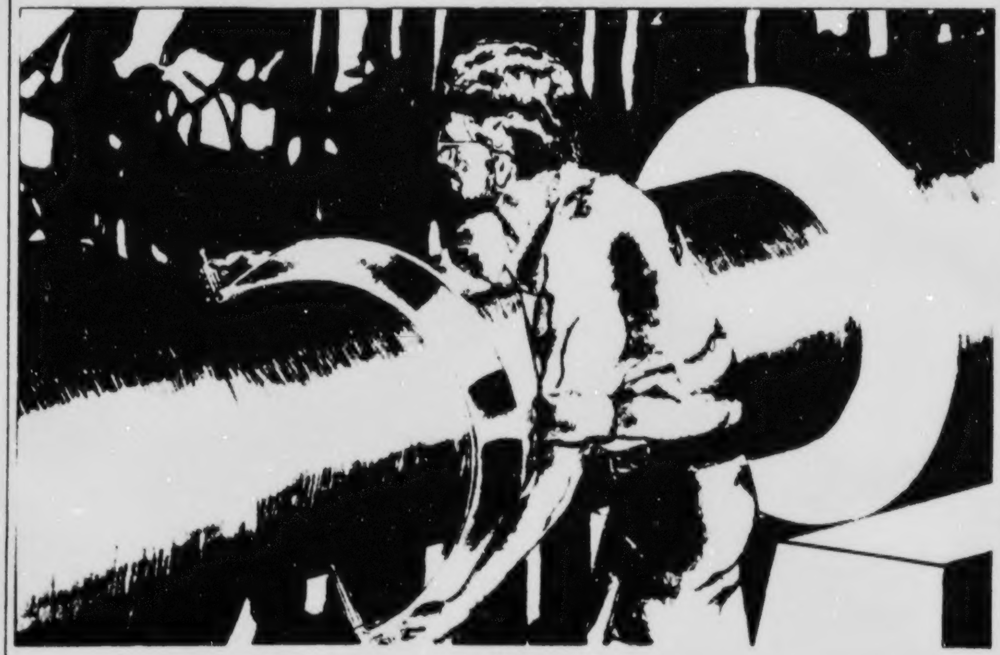
6. State the purpose of and briefly describe how to conduct any of the following individual pump tests:
   a. direction of rotation
   b. vibration
   c. motor load versus time
   d. seal leakage
   e. seal cooling
   f. flow and pressure characteristics
   g. acceleration
   h. coastdown

101

NUCLEAR TECHNOLOGY

MODULE 30-3

VALVE INSPECTION



COURSE 30 MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

MODULE 30-1	Pump Inspection
MODULE 30-2	Pump Functional Testing
⇨ MODULE 30-3	Valve Inspection
MODULE 30-4	Piping Inspection
MODULE 30-5	Sufrace Cleaning Inspection
MODULE 30-6	Protective Coating Inspection
MODULE 30-7	Pressure Vessel Inspection
MODULE 30-8	Rotating Equipment Inspection

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INTRODUCTION

A 1000 megawatt electrical nuclear power plant typically requires over 50 systems for its operation with an average of more than 20 valves per system. Each of these must be carefully inspected and installed.

This module considers all of the major types of valves employed in such a plant. It will examine the characteristics and purposes of each valve and its operation. Also considered in this module are the purposes of the preinstallation and installation inspections as well as the valve testing required for a given valve.

This module should serve as an overview for virtually all the types of valves which would be encountered in a nuclear station. The information presented here is intended for those persons with little or no experience with valves. However, the depth of coverage of this module should also serve to be informative to those with valve inspection experience as well.

MODULE PREREQUISITES

The two previous modules of this course should have been completed.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Name the typical pressure boundary parts of valves.
2. Describe characteristics of given types of valves with respect to functions, operations, and relative pressure loss for gate, globe, check, plug, butterfly, and relief valves.
3. State the purpose and briefly describe the operation of thermostatic and mechanical steam traps.
4. Describe seat leakage characteristics of gate and globe valves.
5. Recognize types of valve actuators and briefly describe the operation of given types of actuators.
6. Name four items of information given by a valve nameplate.
7. State the general purpose of given valve inspections which are typically performed as preinstallation and installation inspections.
8. Describe the role of an installation job package.
9. State the purpose of given valve tests including operability, hydrostatic, check valve functional, seat leakage, stroke time, relief set point, and systems control tests.
10. Briefly describe the performance of hydrostatic, seat leakage, stroke time, relief set point, open-close system control and variable positioning system control tests. Include setup, conduct, and examinations performed.
11. Name six sections of a test procedure and generally describe the content of each.

VALVE TYPES

Basic Parts

Basic parts of a valve have common nomenclature regardless of the type of valve. These basic parts are body, bonnet, disk, seal rings, stem, and actuator which are illustrated in Figure 30-3-1.

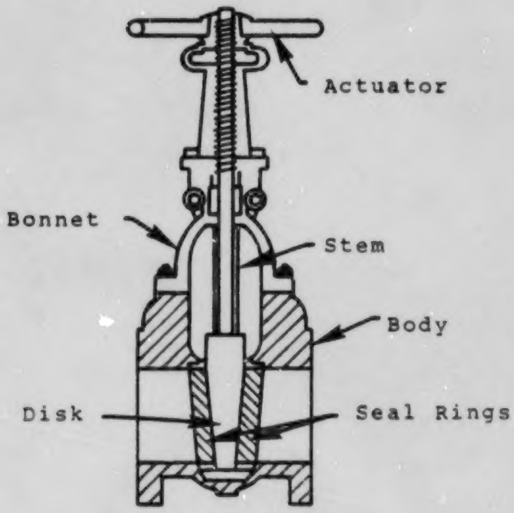


Figure 30-3-1. Basic Parts of Valves

The body is the primary pressure boundary part and serves as the principle element of valve assembly. It provides the seat against which the disk seals off flow. It receives the bonnet through either threaded, bolted, or welded coupling. It receives the inlet and outlet piping through threaded, bolted or welded joints. Valve bodies are either cast or forged and machined at the interfaces with seal rings, bonnet, and inlet and outlet piping.

The bonnet is the next principal pressure boundary part. The bonnet provides a "closure head" for the body and supports the stem, disk and actuator. Bonnets are cast or forged and connected to the body by threaded, bolted, or welded joints. In all cases, the attachment of the bonnet to the body is considered pressure boundary. This means that the bolts or the weld joint which connects bonnet to body are pressure boundary parts. In most valve types, the bonnet also houses the packing or seal around the stem which prevents stem leakage.

The disk is the next principal pressure boundary part. The disk provides the capability to close the flow path. With the disk closed (seated), full system pressure is applied across the disk if the outlet side is depressurized. For this reason, the disk is a pressure boundary part. Disks are typically forged and, in some designs, hardsurfaced to provide good wear characteristics. A fine surface finish of the seating area of the disk is necessary for good sealing when the valve is closed.

Seal rings provide the seating surface for the disk. In some designs, the body is machined to serve as the seating surface and seal rings are not used. In other designs, forged seal rings are threaded or welded to the body to provide the seating surface. In either case, the surface is often hard-faced by welding deposit to improve wear characteristics. A fine surface finish of the seating area is necessary for good sealing when the valve is closed. Seal rings are not considered pressure boundary parts because the body has sufficient wall thickness to withstand design pressure without relying upon the thickness of the seal rings.

The stem translates the motion of the actuator into disk motion. Stems are typically forged and connected to the disk by threaded or welded joints. For valve designs requiring stem packing or sealing to prevent leakage, a fine surface finish of the stem in the area of the seal is necessary. Stems are typically not considered a pressure boundary part.

The actuator operates the stem and disk assembly. Actuators may be manual handwheels, manual levers, motor operators, pneumatic operators, solenoid operators, or hydraulic rams. In some designs, the actuator is supported by the bonnet. In other designs, a yoke mounted to the bonnet supports the actuator. Except for certain hydraulically operated valves, actuators are outside the pressure boundary. Yokes, when used, are always outside the pressure boundary.

Types of Valves

Six basic types of valves are used in a nuclear power plant. These types are (1) gate valves, (2) globe valves, (3) check valves, (4) plug or ball valves, (5) butterfly valves, and (6) relief and safety valves. Each of these types of valves has unique characteristics which determine its application in power plant systems. These unique characteristics exist for a given type of valve regardless of the system which uses the valve.

Gate Valves

Gate valves are used to start or stop fluid flow, but not to regulate or throttle flow. The name "gate" is derived from the appearance of the disk in the flow stream, which is similar to a gate. The highly simplified drawing of Figure 30-3-2 illustrates a gate valve and its schematic symbol.

As indicated in Figure 30-3-2, the disk is completely removed from the flow stream when a gate valve is fully open. This characteristic offers virtually no resistance to flow when the valve is open and, hence, there is little pressure drop across an open gate valve. When the valve is fully closed, a disk to seal ring contact surface exists for 360° and good sealing is provided. With proper mating of disk to seal ring, very little or no leakage occurs across the disk when the gate valve is closed. On opening of the gate valve, the flow path is enlarged in a highly non-linear manner with respect to percent of opening. Also the partially open gate disk tends to vibrate from the fluid flow. For these reasons, gate valves are not used to regulate or throttle flow.

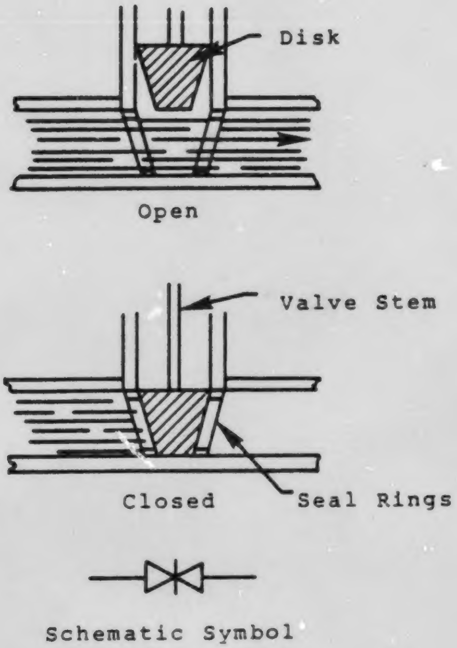


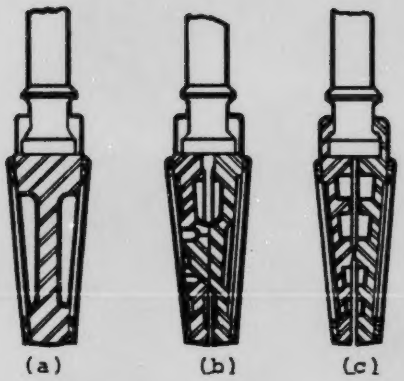
Figure 30-3-2
Simplified Gate Valve and Schematic Symbol

Gate valves are used for start-stop functions. Gate valves may be designed for use at any system pressure. In a system with flow during normal operations, gate valves provide the capability of closing the flow path whenever desired. In a system with no flow during normal operation, gate valves provide the capability to open the flow path when desired. Hence gate valves are either fully closed or fully open dependent upon their specific application.

The disk of gate valves typically provides seating on both the inlet and outlet sides. Disks may be of parallel or wedge design. Parallel disks have seating surfaces which are perpendicular to the flow path. Wedge disks have seating surfaces which form converging angles to the flow path. Wedge disks may be solid, split or flexible as illustrated in Figure 30-3-3. In most cases, wedge disks seal both the inlet and outlet ports when closed. In such cases, the split and flexible wedges provide some automatic adjustment of seating surfaces with wear. In such designs, seat leakage if any tends to increase as differential pressure across the seat increases. Some flexible wedges and most parallel gate disks provide for sealing only one port. In these designs, the high pressure side pushes the disk open on the high pressure side but forces the disk closed on the low pressure side. With such designs, the amount of seat leakage tends to decrease as differential pressure across the seat increases.

Gate valves employ rising stems or non-rising stems. In rising stem gate valves, the stem rises due to actuator motion and lifts the disk. In non-rising stem gate valves, the stem is threaded into a sleeve which is connected to the disk within the bonnet. Radial motion of the stem is translated into vertical motion of the threaded sleeve such that the sleeve and disk rise within the bonnet but the stem does not rise. Rising stem gate valves are used in pressure applications ranging from low to high. Non-rising stem gate valves are used in high pressure applications.

Gate valves are adaptable to any type of actuator. Differential pressure across the disk causes additional friction between the disk and seal rings. The actuator must be capable of overcoming this friction at design differential pressure.



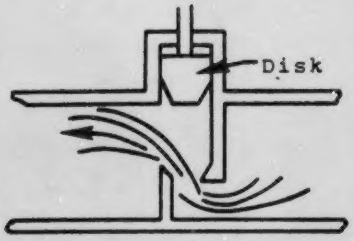
(a)= solid
(b)= split
(c)= flexible

Figure 30-3-3. Types of Wedge Disks

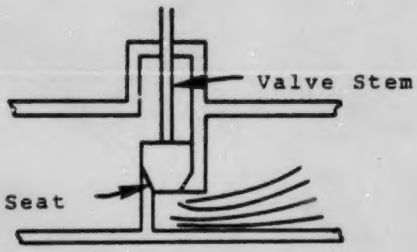
Globe Valves

Globe valves are used to stop, start and regulate fluid flow. The name "globe" is derived from the shape of the disc which is similar to a globe. A simplified globe valve is shown in Figure 30-3-4.

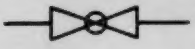
As indicated in Figure 30-3-4, the globe valve disk can be totally removed from the flow path or it can completely close the flow path. With proper mating between the disk and seal ring, very little or no leakage occurs across the disk with the valve closed. In addition, the annular space between disk and seal ring gradually closes as the valve is closed. This characteristic gives the globe valve good throttling ability which permits its use in regulating flow. Therefore, the globe valve is used not only for start-stop functions but also for flow regulating functions.



Open



Closed



Schematic Symbol

Figure 30-3-4
Simplified Globe Valve and Schematic Symbol

It is generally easier to obtain very low seat leakage with a globe valve as compared to a gate valve. This is because the disk to seal ring contact is more at right angles which permits the force of closing to tightly seat the disk.

Globe valves can be arranged such that the disk closes against the direction of fluid flow or such that the disk closes in the same direction of fluid flow. When the disk closes against the direction of flow, the kinetic energy of the fluid impedes closing but aids opening of the valve. When the disk closes in the same direction as flow, the kinetic energy of the fluid aids closing but impedes opening of the valve. The characteristics make the globe valve preferrable to the gate valve when quick acting stop valves are necessary.

In any globe valve, the fluid follows a somewhat tortuous path through the valve. This characteristic causes restriction to flow and results in a larger pressure loss across the globe valve as compared to the gate valve. Even with the larger pressure loss, the globe valve is preferrable to the gate valve whenever throttling characteristics or quick-acting characteristics are important.

Other features of the globe valves are similar to those for gate valves. Rising or non-rising stems may be used. Any type of actuator may be used. Globe valves may be designed for any system pressure. However, direction of flow and not valve differential pressure determines whether system conditions are aiding or impeding the actuator.

Check Valves

Check valves permit flow in only one direction. The name is derived from the valve's ability to "check" flow in the undesired direction. A simplified check valve and its schematic symbols are illustrated in Figure 30-3-5.

As indicated in Figure 30-3-5, fluid flow from left to right swings the disk out of the flow path and flow is permitted in that direction. If flow is attempted right to left, the flow pushes the disk against the valve seat and flow is prohibited in that direction.

There are three basic types of check valves (1) swing check, (2) lift check, and (3) stop lift check. Any of these may be designed for use at any system pressure.

The swing check valve, which is illustrated in Figure 30-3-6, uses a hinged disk which "swings" in operation. Flow from inlet to outlet swings the disk open. Flow from outlet to inlet swings the disk closed. Swing check valves offer little resistance to flow when open. This type is used in systems where pressure loss in the open

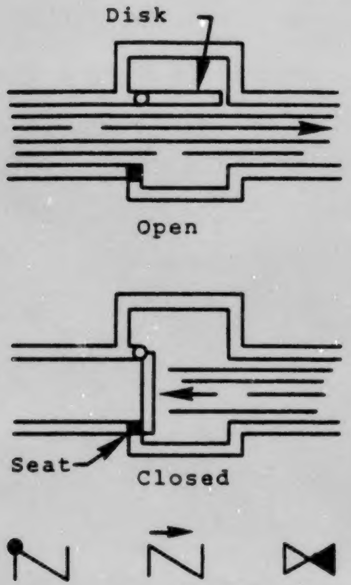

Disk
Open
Seat
Closed

Figure 30-3-5
Simplified Check Valve and Schematic Symbols

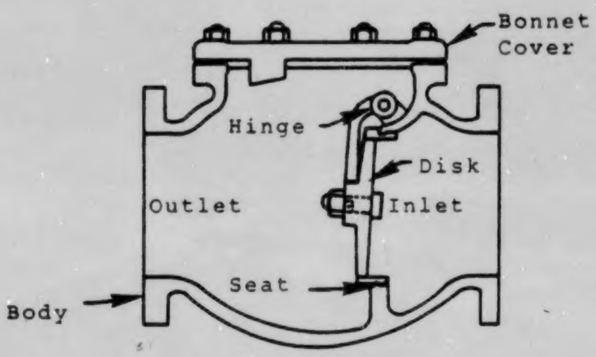

Bonnet
Cover
Hinge
Disk
Outlet
Inlet
Seat
Body

Figure 30-3-6. Swing Check Valve

direction must be minimized

Lift check valves resemble the globe valve. The disk is attached to slide rails on a fixed stem such that the disk is free to open or close with no stem motion. As illustrated in Figure 30-3-7, the disk of the lift check valve "lifts" off the seat when flow is from inlet to outlet. When flow is reversed, the disk seats and prevents reverse flow. Lift check valves cause a relatively large pressure loss in the direction of flow but typically have less reverse flow leakage than the swing check.

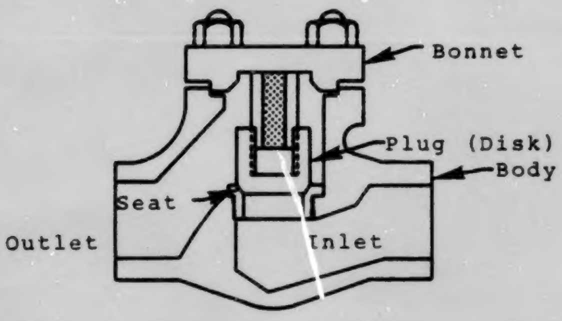


Figure 30-3-7. Lift Check Valve

Stop lift check valves are capable of being forcibly closed by an actuator. As illustrated in Figure 30-3-8, the movable valve stem enters a drilled hole in the disk. When the stem is withdrawn, the disk is free to lift or close dependent on direction of flow. In this condition, the valve is operating as a lift check valve. When the stem is inserted, it forces the disk against the seat. In this condition, the valve serves as a stop valve and prohibits flow in either direction. Stop lift checks are used where the combined functions of check and stop valves are desirable.

Plug Valves and Ball Valves

Plug valves and ball valves are used to stop or start fluid flow. The names are derived from the shape of the disk which resembles a plug or a ball. A plug valve is illustrated in Figure 30-3-9.

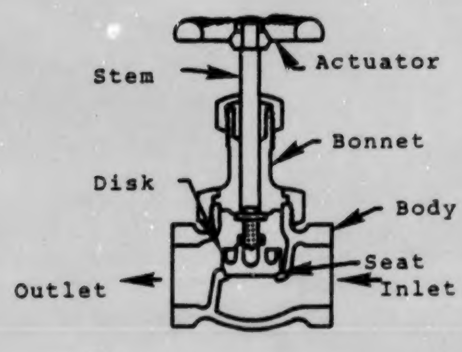

Stem
Actuator
Bonnet
Disk
Body
Seat
Outlet
Inlet

Figure 30-3-8. Stop Lift Check Valve

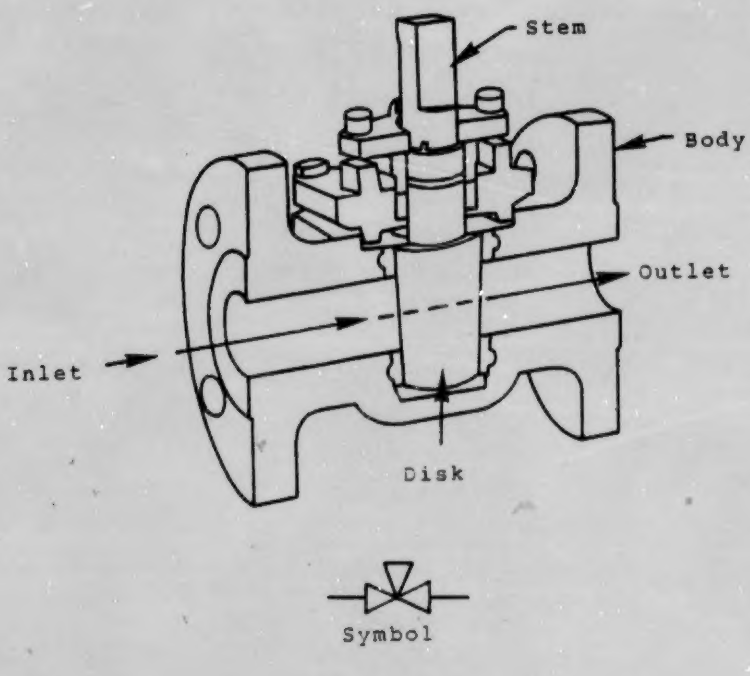

Stem
Body
Outlet
Inlet
Disk
Symbol

Figure 30-3-9. Plug Valve and Schematic Symbol

The body of a plug valve is machined to receive the tapered or cylindrical plug. The disk is a solid plug with a bored passage at a right angle to the longitudinal axis of the plug. In the open position, the passage in the plug lines up with the inlet and outlet ports of the valve body. When the plug is turned 90° from the open position, the solid part of the plug blocks the ports and stops fluid flow. Ball valves function similarly. The primary difference is that a solid ball with a bored passage is used as the disk.

Plug valves and ball valves offer little resistance to flow in the open position and provide for good sealing in the closed position. Differential pressure across the disk has little effect on power needed to open the valve. These valves are relatively "quick opening". Plug and ball valves can be designed for use at any system pressure. The primary disadvantages of plug and ball valves are (1) cost, (2) relatively rapid wear and corrosion of plug-to-body or ball-to-body seals, and (3) inability to regulate flow.

Plug or ball valves are infrequently used in nuclear power plants. In low pressure systems where plug or ball valves might be used, butterfly valves are typically used because butterfly valves are less expensive and offer essentially the same characteristics.

Butterfly Valves

Butterfly valves are used to stop, start, and regulate fluid flow. The name derives from the action of the disk in the flow stream which is somewhat similar to the wings of a butterfly. A butterfly valve is illustrated in Figure 30-3-10.

Butterfly valves typically use a soft, resilient seat made of rubber or neoprene. The disk is rotated about an axis through its centerline and at a right angle to fluid flow. In the fully open position, little resistance to flow exists and pressure loss is minimal. In the fully closes position little seat leakage occurs provided the resilient seat is in good condition. At intermediate positions of the disk, throttling of fluid flow occurs although the flow regulating characteristics are not as good as that of globe valves.

Butterfly valves are used in low pressure systems. They are inexpensive and fairly easy to maintain. For these reasons, they are typically used in circulating water systems of nuclear power plants.

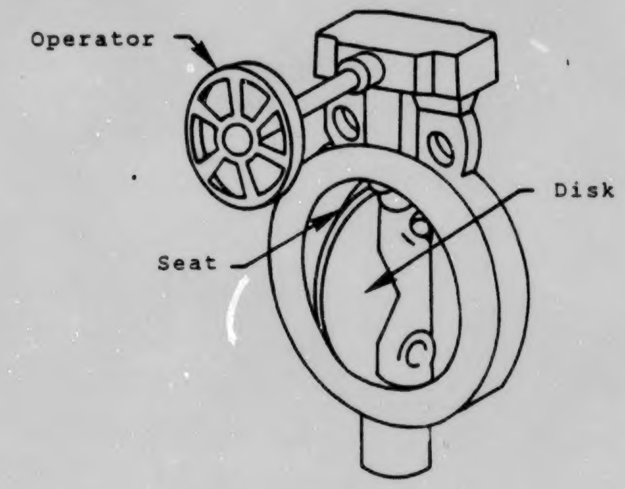


Figure 30-3-10. Butterfly Valve

Relief and Safety Valves

Relief and safety valves prevent equipment damage by relieving accidental over-pressurization of fluid systems. The main difference between a relief valve and a safety valve is the extent of opening at the set point pressure. Relief valves gradually open as the inlet pressure increases above the set point. A relief valve opens only as necessary to relieve the over-pressure condition. Safety valves rapidly pop fully open as soon as the pressure setting is reached. A safety valve will stay fully open until the pressure drops below a reset pressure. The reset pressure is lower than the actuating pressure setpoint. The difference between the actuating pressure setpoint and the pressure at which the safety valve resets is called blowdown. Blowdown is expressed as a percent of the actuating pressure setpoint.

Relief valves are used for incompressible fluids such as water or oil. Safety valves are used for compressible fluids such as steam or other gases. Safety valves can be distinguished by the presence of an external lever at the top of the valve body which is used as an operational check.

A typical relief valve and the schematic symbol for relief valves are illustrated in Figure 30-3-11. As indicated in the figure, system pressure provides a force which is attempting to push the disk off its seat. Spring pressure on the stem is forcing the disk onto the seat. At some pressure determined by spring conpression, system pressure overcomes spring pressure and the relief valve opens. As system pressure is relieved, the valve closes when spring pressure again overcomes system pressure. Most relief and safety valves open against the force of a compression spring. The pressure set point is adjusted by turning the adjusting nuts on top of the yoke to increase or decrease the spring compression.

Pilot-operated relief valves are designed to maintain pressure through a small passage to the top of a piston connected to the stem such that system pressure closes the main relief valve. When the small pilot valve opens, system pressure is relieved from the piston and system pressure under the disk opens the main relief valve. Such pilot valves are typically solenoid operated where the energizing signal originates from pressure measuring systems.

Steam Traps

Steam traps are special types of valves which prevent equipment damage by removing accumulated condensate from steam lines. Steam traps are located at low points of elevation and drain condensate from steam lines without allowing steam to escape. Traps operate on a thermal or machanical principle.

Thermostatic traps are usually found in heating systems. This type of trap operates by thermal expansion of an alloy bimetallic strip or a metal bellows partially filled with a volatile liquid. As illustrated in Figure 30-3-12, the bellows type of thermostatic steam trap operates by expansion and contraction of the volatile fluid within the bellows. Steam causes the fluid to boil, increase pressure within the bellows and close the valve by bellows expansion. If condensate enters the trap, some of the volatile fluid condenses causing the bellows to contract and open the valve.

Mechanical steam traps are used in steam power systems. The most common type of mechanical trap consists of a ball float which rises and falls with the condensate level as illustrated in Figure 30-3-13. As condensate level increases, the ball float rises and opens the valve. As condensate level decreases, the ball float falls and closes the valve. The extent of valve opening is determined by the rise of the float.

Another type of mechanical steam trap is the bucket type. As illustrated in Figure 30-3-14, a bucket connected to the valve floats on the condensate. As long as the bucket floats, the valve is closed. When the trap body is nearly filled with condensate, the bucket, which is physically restrained from floating higher, begins filling with

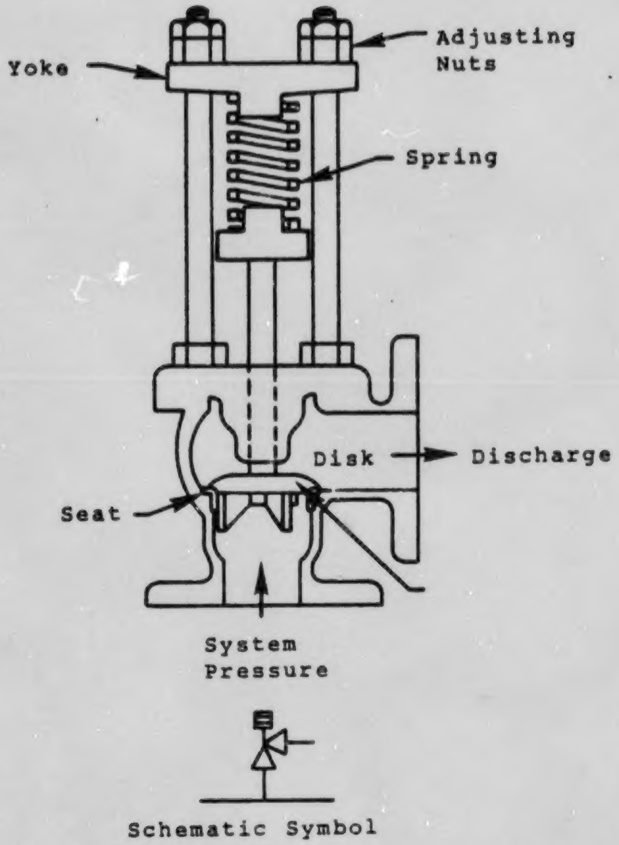
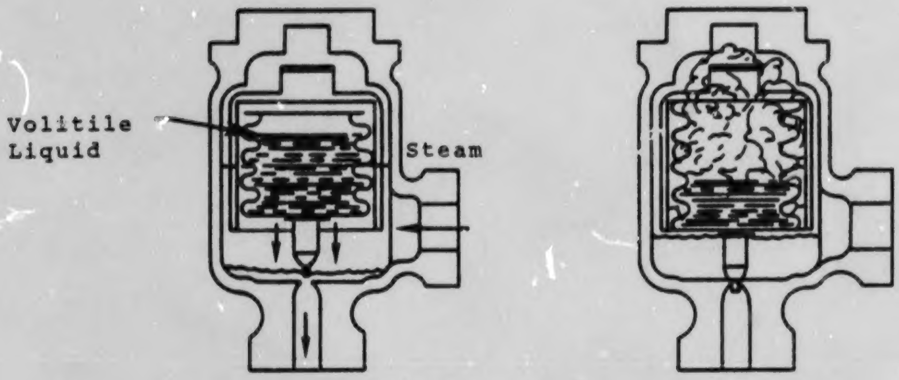

Adjusting Nuts
Yoke
Spring
Disk
Discharge
Seat
System Pressure
Schematic Symbol

Figure 30-3-11. Relief Valve and Schematic Symbol

condensate. When the bucket is essentially full, it sinks and opens the valve fully. The valve remains open until enough condensate has been discharged to permit the bucket to again float.


Volitile
Liquid
Steam

Cool condensate
Condenses liquid,
contracts bellows
and opens valves

Hot steam expands
bellows and closes
valve

Figure 30-3-12
Bellows Type Thermostatic Steam Trap

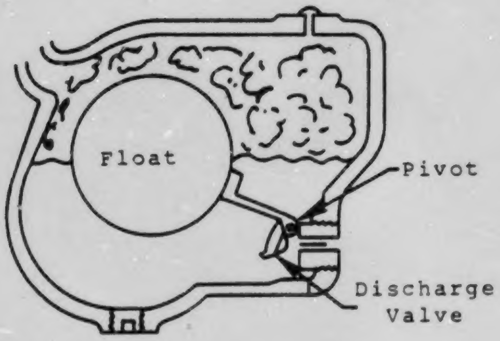

Float
Pivot
Discharge
Valve

Figure 30-3-13. Ball Float Steam Trap

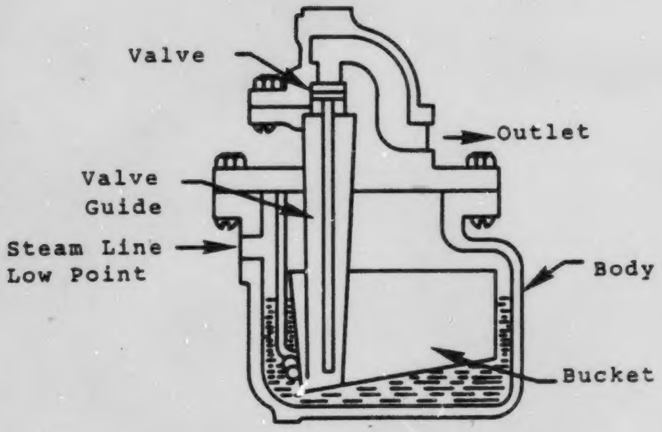


Figure 30-3-14. Bucket Type Steam Trap

VALVE ACTUATORS

Types of Actuators

Engineering selects the type of actuator based on a number of factors including torque necessary to operate the valve and need for automatic actuation. Types of actuators include (1) manual handwheel, (2) manual lever, (3) electrical motor, (4) pneumatic, (5) solenoid, (6) hydraulic piston, and (7) self actuated. All except manual handwheel and lever are adaptable to automatic actuation.

Manual, Fixed or Hammer Actuators

Manual actuators are capable of placing the valve in any position but do not permit automatic operation. The most common mechanical actuator is the handwheel. This type includes (1) handwheels fixed to the stem, (2) hammer handwheels and (3) handwheels connected to the stem through gears.

Handwheels fixed to the stem provide only the mechanical advantage of the wheel. When these valves are exposed to high operating temperatures, valve binding makes operation difficult. A pounding arrangement is used in such cases to facilitate valve operation. The "hammer" handwheel moves freely through a portion of its turn and then hits against a lug on a secondary wheel. The secondary wheel is attached to the valve stem. With this arrangement, the valve can be pounded shut for tight closure or pounded open if it is stuck shut.

If additional mechanical advantage is necessary for a manually operated valve, the valve bonnet is fitted with manually operated gear heads. A special wrench or handwheel attached to the pinion shaft permits one individual to operate the valve where two individuals might be needed without the gear advantage. Because several turns of the pinion are necessary to produce one turn of the valve stem, the operating time of large valves is exceptionally long. The use of portable air motors connected to the pinion shaft decreases the valve operating time.

Electric Motor Actuators

Electric motors permit manual, semi-automatic, and automatic operation of the valve. Motors are mostly used for open-close functions although they are adaptable to positioning the valve to any point opening. The motor is usually a small, reversable, high speed type connected through a gear train to reduce the motor speed and thereby increase the torque at the stem. Direction of motor rotation determines direction of disk motion. The electrical actuation can be semi-automatic as from a push button which starts the motor or automatic, as when the motor is started by a control system. A handwheel which can be engaged to the gear train provides for manual operation of the valve. Limit switches are normally provided to stop the motor automatically at full valve opening and closure. Limit switches are operated either physically by position of the valve or torsionally by torque of the motor.

Hydraulic Actuators

Hydraulic actuators provide for semi-automatic or automatic positioning of the valve. These actuators use a piston to convert a signal pressure into valve stem motion. Hydraulic fluid is fed to either side of the piston while the other side is drained or bled. Water or oil is used as the hydraulic fluid. Solenoid valves are typically used for automatic control of the hydraulic fluid to direct either opening or closing of the valve. Manual valves can also be used for controlling the hydraulic fluid and thus provide semi-automatic operation.

Pneumatic Actuators

Pneumatic actuators provide for automatic or semi-automatic valve operation. These actuators translate an air signal into valve stem motion by air pressure acting on a diaphragm or piston connected to the stem. Pneumatic actuators are used in throttle valves for open-close positioning where fast action is required. When air pressure closes the valve and spring action opens the valve, the actuator is termed direct-acting. When air pressure opens the valve and spring action closes the valve, the actuator is termed reverse-acting. Duplex actuators have air supplied to both sides of the diaphragm. The differential pressure across the diaphragm positions the valve stem. Automatic operation is provided when the air signals are automatically controlled by circuitry. Semi-automatic operation is provided by manual switches in the circuitry to the air control valves.

Self-Actuated Valves

Self-actuated valves use system fluid to position the valve. Relief valves, safety valves, check valves, and steam traps are examples of self-actuated valves. All of these use some characteristic of the system fluid to actuate the valve. No source of power outside the system fluid energy is necessary for operation of these valves.

Solenoid Actuated Valves

Solenoid actuated valves provide for automatic open-close valve positioning. Most solenoid actuated valves also have a manual override which permits manual positioning of the valve for as long as override is manually positioned. Solenoids position the valve by attracting a magnetic slug attached to the valve stem. In single solenoid valves, spring pressure acts against the motion of the slug when power is applied to the solenoid. These valves can be arranged such that power to the solenoid either opens or closes the valve. When power to the solenoid is removed, the spring returns the valve to the opposite position. Two solenoids can be used to provide for both opening and closing by applying power to the appropriate solenoid.

Single solenoid valves are termed fail open or fail closed dependent on the position of the valve with the solenoid deenergized. Fail open solenoid valves are opened by spring pressure and closed by energizing the solenoid. Fail closed solenoid valves are closed by spring pressure and opened by energizing the solenoid. Double solenoid valves typically fail "as is". That is, the valve position does not change when both solenoids are deenergized.

Speed of Power Actuators

Plant safety considerations dictate valve speeds for certain safety related valves. Where a system must be very quickly isolated or opened, very fast valve actuation is required. Where the opening of a valve results in injection of relatively cold water to a hot system, slower opening is necessary to minimize thermal shock. Engineering design selects the actuator for safety related valves based on speed and power requirements and availability of energy to the actuator.

In general, fastest actuation is provided by hydraulic, pneumatic, and solenoid actuators. However, solenoids are not practical for large valves because their size and power requirements would be excessive. Also, hydraulic and pneumatic actuators require a system for providing hydraulic or pneumatic energy. The speed of actuation in either case can be set by orificing the hydraulic or pneumatic lines.

Electrical motors provide relatively fast actuation. Actual valve speed is set by the combination of motor speed and gear ratio. This combination can be selected to provide full valve travel within a range from about two seconds to many seconds.

Valve Position Indication

The reactor operator requires indication of the position of certain valves to permit knowledgeable operation of the plant. For such valves, remote valve position indication is provided in the form of position lights which indicates if valves are open or closed. Remote valve position indication circuits use a position detector which senses stem and disk position or actuator position. One type of position detector is the mechanical limit switch, which is physically operated by valve movement. Another type is magnetic switches or transformers which sense movement of their magnetic cores which are physically operated by valve movement.

Local valve position indication refers to some visually discernable characteristic of the valve which indicates valve position. Rising stem valve position is indicated by the stem position. Nonrising stem valves sometimes have small mechanical pointers which are operated by the valve actuator simultaneously with valve operation. Power actuated valves typically have a mechanical pointer which provides local valve position indication. On the other hand, some valves do not have any feature for position indication.

PREINSTALLATION INSPECTION

Purpose and Scope

Preinstalltion inspections of valves verify that the valve and the installation area comply with specified requirements. Preinstallation inspections are required for valves intended for safety related systems. When a valve is received at the nuclear power plant site, it is receipt inspected for conformance with the valve design specification. Accepted valves are tagged with an acceptance tag and placed into storage until it is needed for installation. Preinstallation inspection confirms that the identity and condition of the valve is maintained. Installation areas are inspected to verify that procedures, trained personnel, and installation equipment are available as required by the system design specification and installation drawings. These installation inspections are applied to (1) identification, (2) processes and procedures, (3) valve physical conditions, and (4) site conditions.

Identification Inspections

The installation contractor must establish a quality assurance program which ensures items are properly installed into their correct location as specified by installation drawings. The quality assurance program provides for maintaining lists or procedures which designate the exact components to be installed in a given system. At release of a valve from storage to the installation area, the inspection activity confirms that the designated valve is in fact released.

Valve identification is provided by the name plate and the accept tag. The data on the name plate is verified as correct by receiving inspection and thereafter the name plate is used as acceptable indication of valve identity. The valve design specification stipulates what is required on the name plate. It typically requires (1) valve manufacturer's name, (2) type of valve, (3) design pressure and temperature, (4) code classification, (5) valve serial number, and, (6) national board number.

Preinstallation inspectors compare name plate data and the accept tag data with the installation procedures to confirm that the correct valve is released for installation. Also, a roving inspector is typically assigned to periodically check released valves to confirm that their identity is maintained.

Inspection of Processes and Procedures

Installation procedures and drawings are prepared for use by the installation contractor. For a given installation activity, the procedures and drawings applicable to that activity are collectively termed "job package". The job package may be attached to the component at release from storage or it may be issued to the supervisor of the installation group. The job package delineates all necessary instructions for installing an item such as a valve.

Preinstallation inspectors confirm that a complete job package is on hand and that its provisions are met. This inspection may be on a roving basis such that an inspector proceeds from one installation activity to another as checks are completed. Checks are typically made to verify (1) availability of approved procedures and drawings, (2) qualification of personnel as required, (3) compliance with prerequisites, (4) availability of necessary handling and fixturing devices, and (5) compliance with safety requirements.

- Approved procedures and drawings - In addition to confirming that the correct job package is available, the inspector checks for other procedures which are required by the installation procedure or drawing. Such other procedures typically involve special processes which will be required for the installation work. Examples include welding procedures, cleaning procedures, heat treating procedures and nondestructive examination procedures.

- Qualification of personnel - The inspector confirms that persons assigned to the installation are qualified if formal qualifications are required. Welders and nondestructive examination personnel are required to be qualified. Dimensional and visual inspectors may also be required to be qualified.
- Compliance with prerequisites - The installation procedure specifies any prerequisites which must be met prior to installing a valve. Examples include removal of packing and plugs which protected the valve internals, and cleaning the general area.
- Handling and fixturing - Dependent on the type and size of valve, various handling equipment and fixtures are necessary for safe movement and positioning of the valve. The inspector verifies availability of such equipment as specified by the job package.
- Safety - The inspector verifies compliance with safety precautions stipulated by the job package. For valve installation, the safety requirements are typically those associated with routine installation activities such as use of hard hats and eye protection.

Inspection of Valve Physical Conditions

During the inspection of installation processes and procedures, the inspector also checks the physical condition of the valve. These checks insure that (1) the quality of the valve has been maintained, (2) any prior reported nonconformances have been corrected, and (3) the valve is adequately clean for installation.

Checks on maintenance of valve quality look for physical damage from mishandling and for unique conditions applicable to the valve. Examples of unique conditions are:

- Weld end preparations are undamaged for valves which will join inlet or outlet piping by welding.
- Threads are undamaged for valves which will join inlet and outlet piping by threaded union.
- Excessive rusting has not occurred.
- Protective caps and plugs are kept in place until installation begins.

Inspection of Site Conditions

During the inspection of installation processes and procedures, the inspector also checks site conditions for compliance with the requirements of the job package. These checks verify that site conditions have been established as required to avoid adversely affecting the quality of the valve. Examples include:

- Protection from adjacent installation activities such that there is little risk of damage to the valve.
- Protection from inclement weather such as snow, rain, sleet, etc.
- Installation of permanent or approved temporary supports on which the valve will be mounted.

INSTALLATION INSPECTIONS

Purpose and Scope

While preinstallation inspections verify readiness to proceed with installation, installation inspections verify that required quality is obtained by the installation work. To accomplish this purpose, critical steps in the installation process are selected for inspection and other installation steps are inspected on a roving basis. These inspections encompass (1) control of procedures and processes, (2) nondestructive examinations, (3) work in progress, and (4) final installation.

Control of Procedures and Processes

Inspections on the control of procedures and processes verify that established controls are being implemented throughout the installation time cycle. These inspections are typically performed on a roving basis and check for procedural compliance by the various steps of installation work. These inspections typically check for (1) control of revisions to procedures and drawings, (2) use of approved procedures and materials by qualified personnel, (3) indication of quality status, (4) compliance with sequence, (5) control of nonconformances, (6) recording as-builts, and (7) completeness of inspections and tests:

- Control of revisions to procedures and drawings - The procedures and drawings contained or referenced by the job package may require revision for a number of reasons. Whenever a job package has been released to the installation contractor, any subsequent revision to applicable procedures or drawings must result in providing to the installation contractor the revised document. Installation inspections confirm that the latest approved revision levels of procedures and drawings are in use by the installation contractor.
- Use of qualified personnel, procedures, and materials - Installation inspections confirm that personnel actually performing the work are qualified as required, that procedures in use are qualified or approved, and that materials being used are those specified by the procedures and drawings. Examples of

materials include threaded fasteners, welding materials, and stem packing.

- Indication of quality status - As installation proceeds, the status of installation including inspections and tests must be clearly identifiable. Such indication of status may be provided by inspection reports, tagging the valve or signoff of installation check lists. The installation inspector confirms that indication of quality status is maintained.
- Compliance with sequence - The job package includes the sequence of steps for proper installation, inspection and test of valves. The installation inspector verifies compliance with the specified sequence.
- Control of nonconformances - Inspections and tests required by the job package may identify nonconforming conditions. In such cases, the valve is tagged as nonconforming and a nonconformance report is initiated. Engineering determines what correction of the nonconformance is necessary and issues appropriate instructions. Until completion of the correction, the valve status must be maintained as nonconforming. The installation inspector verifies the tagging of nonconforming valves and maintenance of such tagging until the nonconformance is corrected.
- Recording of as-builts - The job package may require that certain dimensions be accorded to reflect the as-built values of the installed valve. For example, the actual, installed location of the valve inlet and outlet nozzles with respect to a datum may be needed to permit fabrication of a piping assembly which will eventually connect to the valve. For pressure boundary valves subject to the ASME Boiler and Pressure Vessel Code, an installation

data form is completed which lists each installed valve. The installation inspector verifies that required as-built information is recorded as installation progresses and that the installation data form is completed.

- Completeness of inspection and test - The job package stipulates the inspections and tests to be performed during the installation process. The installation inspector verifies that inspection and test reports are prepared for each required inspection and test.

Nondestructive Examinations

Nondestructive examinations of valve installations are typically required only for welded joints such as welds between inlet and outlet piping and valve body. Valves with bolted or threaded pipe connections do not require nondestructive examinations during valve installation. When required, nondestructive examinations may consist of liquid penetrant, magnetic particle, radiography or ultrasonic tests. For weld joints in magnetic materials, magnetic particle and radiography are typically required. For weld joints in nonmagnetic materials, liquid penetrant and radiography are typically required. For welds which are subject to later inservice inspection by ultrasonic testing, an ultrasonic test is performed at installation to establish a known "base-line" for comparison with later inservice ultrasonic tests. Whenever nondestructive testing is required, it must be performed to an approved procedure by qualified persons.

Work in Progress

Installation inspections are planned for work in progress to ensure that critical installation requirements are met. For critical requirements, inspection hold points are established which require installation work to stop at such points until the inspection is performed. For installation work steps considered not critical, a roving inspector periodically checks for compliance with the job package. Typical hold points for valves include:

- Orientation - Inspection verifies that the valve is mounted with inlet, outlet and actuator connections in the correct orientation. Check valve orientation is particularly important.
- Torquing of threaded fasteners - Bolted mounts, pipe-to-body flanges, and pipe hangers are torqued to specified values. The installation inspector typically witnesses torquing of threaded fasteners.

The remainder of installation work is typically checked periodically by a roving installation inspector. Such addition work activities include cleaning, welding, pipe fitting, housekeeping, and protection of valve internals from foreign materials.

Final Installation Inspection

Once the valve is installed, the installation inspector makes a final inspection which serves to report the acceptance of the installation. The final inspection verifies that:

- All steps of the job package have been completed including all inspections and tests and correction of any nonconformances.
- External connections have been completed including piping and power connections as required.
- Limit switches, interlocks, and stops are installed.
- All specified mounts, hangers, and supports are installed.
- All specified temporary protective plugs, covers, and strainers are in place.

At this point, installation inspection has verified that the correct valve has been properly installed in the right location. The valve is now ready for testing. However, the entire system which contains the valve must typically be installed prior to conducting most tests.

VALVE TESTS

Tests by Manufacturer

Design specifications for each type and kind of valve are prepared by or under the direction of the owner of the nuclear power plant. The valve manufacturer produces valves in accordance with these design specifications and performs valve tests as specified by them. Hydrostatic testing of assembled valve is required for most valves. In addition, certain valves may require seat leakage tests and stroke time tests. Also, a sample number of each design of relief and safety valves is subjected to full flow pressure relief testing. Each relief and safety valve is tested for proper set point pressure.

Tests by the valve manufacturer ensure that the valve satisfies design requirements for that valve. After the valve is installed at the power plant site, tests are conducted as appropriate to the function and importance of the valve with respect to safe operation of the plant. The tests performed at the plant site are the same type as those performed by the valve manufacturer except that system design requirements apply.

Tests after Installation

Thousands of valves are used in the various systems which comprize the nuclear power plant. These valves differ by types, pressure ratings, sizes, materials, and type of actuators. The extent of testing of any given valve is based on the safety related function of the valve as stipulated by engineering. About 500 valves are subjected to more than a simple operability test. The types of testing include (1) valve operability, (2) hydrostatic or pneumatic pressure, (3) seat leakage, (4) stroke time, (5) relief set point, and (6) control system tests. The techniques for performing these tests are essentially the same regardless of valve type.

Valve Operability Tests

Valve operability tests verify that the installed valve operates without binding. This test is an installation tests which is applied to gate, globe, plug, ball, and butterfly valves upon completion of their installation. The test is a relatively simple test and is performed by using the installed actuator and confirming operation of the valve through a complete cycle, i.e. open-close-open or close-open-close.

Automatic controls which may be associated with power valve actuators are not tested by the operability test. Such controls are tested later as system control tests. However, the operability test verifies functioning of limit switches on power actuators as do the system control tests.

Valve operability tests are performed prior to filling the system for hydrostatic or leak testing. Satisfactory completion of the operability tests ensures that the valves are operable and indicates that their use should be reliable during later preoperational testing.

Hydrostatic and Pneumatic Pressure Tests

Most power plant fluid systems are pressure tested as a preoperational test. Pressure tests of the system also tests valves within the system. These tests verify that valve pressure boundary parts do not leak except as may be permitted by the design specification.

Valves within the system are considered in two categories. First, certain stop valves are closed to establish the boundary limits of the system. The extent of testing of these boundary valves depends on whether test pressure is permitted by the valve arrangement to be applied to the bonnet. Second, valves between the boundary isolation valves are open to permit test of the entire system. Test pressure is applied to all pressure boundary parts of these valves except perhaps the disks.

Most system pressure tests are hydrostatic tests. The system boundaries are established and isolated by closing stop valves and blanking openings which may exist at the time. The system is then filled with water and vented at all high points to ensure removal of air. This may require loosening of stem packing glands of large valves until a stream of water leaks from around the valve stem. Stem packing glands are then retorqued to the specified amount. Retorquing may be designated as a witness point by a quality assurance representative. After filling and venting is completed, system pressure is increased by positive displacement pumps discharging into the system. Visual inspections for leaks are performed at designated pressure increments and at full test pressure. Full test pressure is typically 120% of design pressure.

Visual inspection for hydrostatic leaks in valves gives particular attention to valve stem packing, bonnet-to-body joint, body-to-pipe joints for both inlet and outlet piping, and external surface areas of the body and bonnet. Threaded connections, bolted joints and stem packing are the most prevalent locations of leaks. Welded joints, bodies, and bonnets may contain leaks in the form of through-wall cracks. Closed valves which establish system boundary may permit seat leakage. Such seat leakage is detectable by drainage from downstream drain lines if direct visual observation of the seat is not possible.

System which must be pressure tested but which cannot support the weight of water or where the water cannot be completely removed as required are pneumatically pressure tested. After isolation of system boundaries, air is charged into the system to the designated test pressure. With the system at test pressure, system pressure is monitored and a bubble solution is applied to mechanical and welded joints to examine for leak.

Stop valves which provide pressure isolation functions for systems also require pressure testing of disks. Oftentimes these are the same valves used as boundary isolation valves for the system pressure test. However, if valves which require pressure tests of disks are not boundary isolations for system tests, another pressure test is required using such valves as the new boundary isolations.

Acceptance criteria for leaks with respect to valves typically includes (1) no detectable leak through wall and at body-to-pipe and bonnet-to-body joints and (2) leaks at stems and seats only as permitted by the design specification. The maximum permissible leak rate for stems and seats is dependent on the functions of the specific system and the valves being tested. The design specification stipulates whether detectable leakage is permitted and, if so, the maximum leak rate.

Check Valve Functional Tests

Check valve functional tests verify that check valves permit flow in the desired direction and prohibit flow in the undesired direction. These tests are normally performed in conjunction with either hydrostatic tests or system flow tests.

One common use of check valves is in systems with parallel flow paths but flow in only one path is desired. An example is the parallel connection of centrifugal pumps as illustrated in Figure 30-3-15.

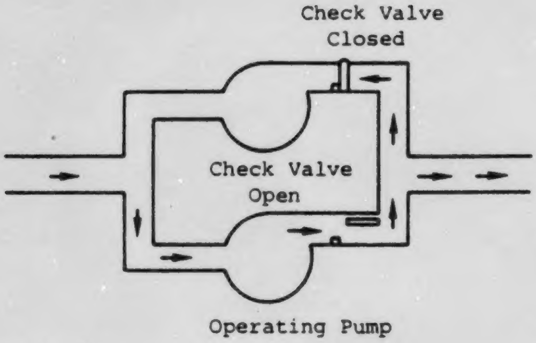
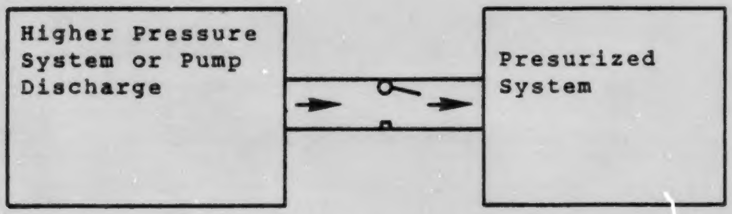


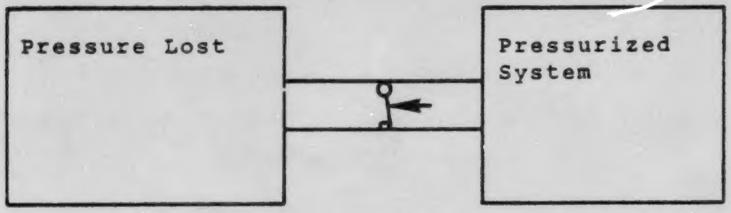
Figure 30-3-15. Check Valves in Parallel Pump System

As illustrated in Figure 30-3-15, discharge from the operating pump attempts to reverse flow through the idle pump. If this were to happen, most of the flow would go through the idle pump with little flow to the system which invariably offers more resistance to flow. Reverse flow through the idle pump is prevented by the check valves. Testing of such check valves is performed by operating each pump in succession and observing pump discharge pressure. If the check valve for the idle pump permits reverse flow, pump discharge pressure would be lower than anticipated. Also, "windmilling" of the idle pump by reverse flow could be detected visually by observing the pump shaft.

Another common use of check valves is to prevent reverse flow in systems should a reverse pressure situation arise. Flow from a pressurized system to a lower pressure system could reverse if pressure were lost in the supply system. Fluid transfer by pump from one system to a higher pressure system could reverse if pumping power were lost. Check valves in the flow lines prevent such reverse flow as illustrated in Figure 30-3-16.



(a) Normal Flow



(b) Reverse Flow Prevented

Figure 30-3-16
Check Valve Prevention of Reverse Flow

Testing of check valves used to prevent reverse flow requires application of a differential pressure across the valve in the reverse flow direction. For preoperational testing, this is accomplished by a positive displacement pump connected between the outlet side of the check valve and a stop valve in the line. Pressure in the line is increased to test pressure and pump discharge is secured. Either pressure stability in the line or no leakage from a drain on the inlet side of the check valve indicates proper functioning of the check valve. If required by the system design specification, seat leakage of the check valve in the reverse flow direction is also measured.

Seat Leakage Tests

Relatively few valves require seat leakage tests. Those stop and check valves are tested whose seat leakage is important with respect to safety related functions. Such valves have specified maximum seat leak rates at designated differential pressures across the disk. The differential pressures are those anticipated when the valve performs its safety related function. The seat leakage test verifies that actual seat leakage at the specified differential pressure is less than maximum specified.

Seat leakage tests are performed by establishing specified differential pressure across the disk in the same direction as that experienced during the safety related function of the valve. Because various modes of plant operation may result in more than one differential pressure of concern, seat leakage tests may be required at more than one differential pressure.

Seat leakage tests may be performed in conjunction with hydrostatic tests if test pressures are identical. If lower pressures are required for the seat leakage tests, the tests are typically performed immediately after hydrostatic testing. A valve may also be tested for seat leakage by pressurizing only a portion of the system. In any of these circumstances, the basic test arrangement is similar to that illustrated in Figure 30-3-17.

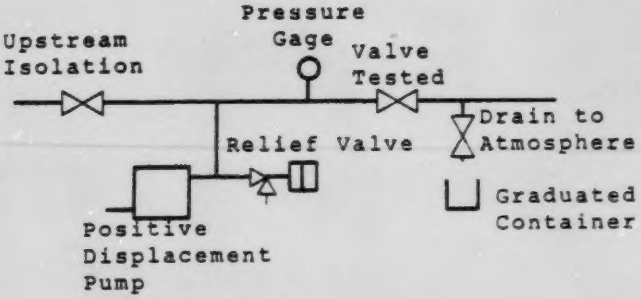


Figure 30-3-17. Seat Leakage Test Basic Configuration

As indicated by Figure 30-3-17, the basic equipment necessary for seat leakage tests are test pump, pressure gage, and graduated collection container. With test pressure applied, seat leakage is collected for a timed interval. The volume of leakage collected divided by the collection time equals the leak rate.

Stroke Time Tests

Stroke time tests verify that time of full valve travel is within specified limits. This test applies to safety related valves whose time of opening or closing is important to safety features of the system. Examples of quick acting valves include those used for containment isolation and containment spray. An example of a deliberately slow acting valve is the pressurizer spray control valve in a pressurized water reactor plant.

Valves which require stroke time tests may be actuated automatically or semi-automatically in normal operations. But for stroke time testing, push buttons, switches, or manual overrides on control valves are used to apply power to the actuator, i.e. semi-automatic actuation is used. In most cases, a stop watch provides sufficient accuracy for measurement of stroke time. If more accurate measurement is needed, chart recorders are used with input signals from valve indication and actuator power circuits. The time is measured from the time of applying power to the actuator until the time of completion of full valve travel. Typical times are from 2 to 8 seconds for quick acting valves.

Relief and Safety Valves Setpoint Tests

Setpoint tests of relief valves and safety valves verify that the valve opens and reacts within specified pressure limits. These tests are not to be confused with "full flow" relief and safety valve tests. Full flow tests are performed at special testing facilities where an over pressure can be maintained at full rated flow of the valve when it is fully open. Such tests are used to "qualify" a relief or safety valve design and are beyond the testing capabilities at a nuclear power plant site.

Self-actuated relief or safety valves are removed from their system and tested at special test stands. However, initial set point testing at the test stands may occur before installation of the relief into the plant system. Set point tests are not performed with the self-actuated relief installed because there is some risk of damage to the system. Typical test arrangements are illustrated in Figure 30-3-18.

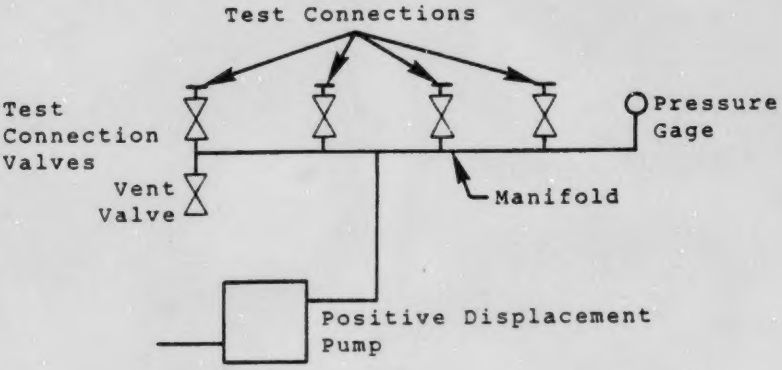


Figure 30-3-18
Basic Arrangement for Set Point Testing

Referring to Figure 30-3-18, a test manifold with multiple test connections permits mounting of self-actuated relief or safety valves to each test connection and valving in the relief to be tested. This arrangement saves time in conducting tests of many reliefs. With reliefs mounted to the test connections and all test connection valves closed except one, the pump is started. When water discharges from the vent, the vent valve is closed. When the relief with the test connection valve lifts, the pressure is noted at the point of lifting and again at reseating if reseating limits are also specified. Then if specified limits are not met, valve spring tension is adjusted by turning the adjusting nuts in the appropriate direction. The relief valve is then retested by closing the vent. When lift point limits are met and with the vent open to lower pressure, the test connection valve for the next relief is opened and the test connection valve for the relief already tested is closed. The vent is then closed and pressure rises until the lined-up relief lifts. This sequence is followed until each relief is verified to lift within specified limits.

Relief having solenoid actuated pilot valves are tested while installed into the plant system. For these tests, the system need not be fully pressurized. A test signal in the pressure indicating circuitry is used to simulate pressure. The test signal actuates a bistable at its setpoint which in turn actuates the solenoid. The bistable set point is adjusted to coincide with the designated relief set point.

Actual opening of the pilot actuated relief is verified by one of several ways. If system temperature is above ambient, increased temperature downstream of the relief indicates that the relief has opened. A drain to atmosphere downstream of the relief may be used. Also, effect on system pressure or level may be used.

Control System Tests

Control system tests verify that automatic positioning of valves occurs as designed. These tests apply to those relatively few valves which are automatically positioned by plant parameters such as pressure, temperature, flow, and level. Control systems may provide open-close functions at some setpoint or may provide continuous positioning in proportion to selected plant parameters.

The block diagram of Figure 30-3-19 illustrates a valve control system which serves an open or close function. The plant parameter is sensed by the detector which gives a proportional signal to the level indicating circuitry. The value of the parameter is read on the indicating meter and continuously supplied to the bistable. The bistable operates when the parameter value reaches the setpoint of the bistable. The bistable may be designed for actuation at its setpoint on an increasing parameter value or a decreasing parameter value. When the bistable actuates, it operates a control device which applies power to the valve actuator. The control device is a circuit breaker or motor controller for motor actuated valves and typically a solenoid operated valve for hydraulic and pneumatic actuators. If the valve to be controlled is solenoid operated, the bistable directly operates the solenoid. When the control device is operated by the bistable, power is applied to the valve actuator to either open the valve if it is normally closed or to close the valve if it is normally open. Typically, an indicator light or alarm signals the reactor operator that the control system has ordered valve actuation.

The open-close control system may monitor more than one plant parameter. In such cases, a detector, level circuitry and bistable for each parameter are provided in parallel. The output of each bistable may feed through an "OR" or "AND" circuit. OR circuits permit any one of the bistables, and hence any parameter, to actuate the valve. AND circuits require output from all bistables or any combination of bistables to actuate the valve.

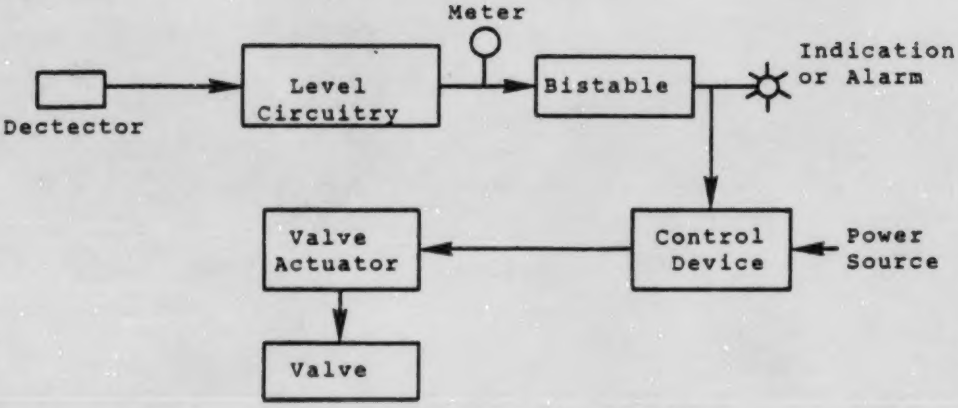

Meter
Indication or Alarm
Level Circuitry
Bistable
Dectector
Valve Actuator
Control Device
Power Source
Valve

Figure 30-3-19. Open-Close Control System

Tests of open-close control systems are performed by simulating the parameter value from the level circuitry. The operation of the bistable, control device, and valve actuator are observed and the parameter level at which actuation occurs is compared to the specified set point. The bistable is adjusted as necessary to initiate valve actuation at the specified set point.

The block diagram in Figure 30-3-20 illustrates a continuous positioning control system. This type of system is used for adjusting throttle valves to regulate flow. For example, pressurized water reactors use this type system to control steam generator water level by regulating feed flow. Boiling water reactors use this type of system for controlling reactor vessel water level. The controlling plant parameters in these examples are typically steam flow, feed flow, and water level.

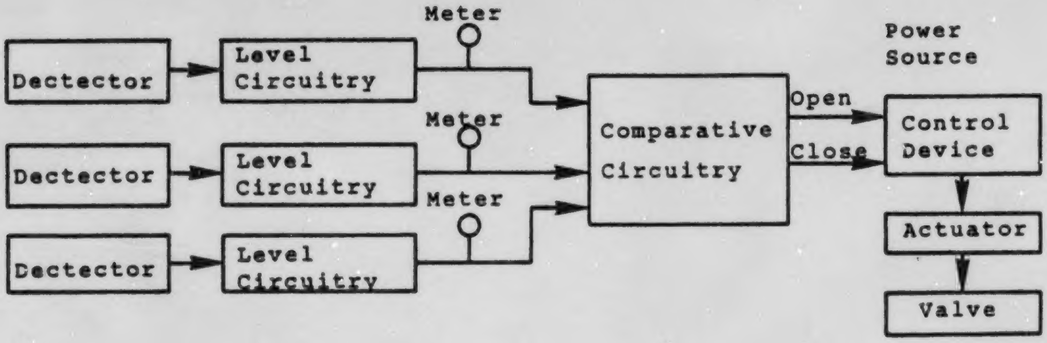

Meter
Meter
Meter
Dectector
Dectector
Dectector
Level Circuitry
Level Circuitry
Level Circuitry
Comparative Circuitry
Open
Close
Power Source
Control Device
Actuator
Valve

Figure 30-3-20. Variable Position Control System

The circuitry for variable position control systems is similar to that for open-close control systems except that comparative circuitry is substituted for bistables. The comparative circuitry continuously compares the plant parameters and issues a signal when an "out-of-balance" condition exists. The output signal is an open or close signal dependent on which direction of valve movement would restore balance to the parameters. Using the example of steam generator water level control, if steam flow exceeds feed flow a comparator initiates opening of the feed water throttle valve until feed flow equals steam flow. The third parameter typically has an overriding effect. For example, if steam flow exceeds feed flow but water level is too high, a valve opening signal does not occur until level decreases sufficiently to remove the overriding effect.

Variable position control systems are tested by simultaneously simulating plant parameters. At various combinations of parameter values, valve positioning is observed and compared with design requirements. Adjustments are made as necessary to the comparative circuits to provide for proper valve positioning.

TEST PROCEDURES

Purpose

Written test procedures are used to more positively ensure the proper performance of testing. Procedures are prepared for each type of valve test except for installation operability testing. The installation job package contains necessary instructions for ensuring valve operability and with the possible exception of certain power actuated valves, separate procedures are unnecessary for operability testing. As previously noted, most valve testing is performed in conjunction with preoperational testing and cold functional testing of systems containing the valve. These tests are repeated for safety related valves at intervals during the life of the plant to verify continued satisfactory functioning of safety related valves.

Content

Each test procedure provides instruction within at least seven topics. These topics are (1) title, number and revision of the procedure, (2) test objectives, (3) test equipment, (4) prerequisites, (5) limitations, (6) procedure, notes and cautions, and (7) acceptance criteria.

- Title, number, and revision - Each test procedure is uniquely identified by title, number, and revision to permit convenient reference to a given procedure. The title typically reflects the nature of the test, e.g., "stroke time testing of High Pressure Safety Injection Valves." The number is a nonrepetitive assigned number selected arbitrarily or in accordance with a system numbering scheme. The revision is indicated by ascending numerical or alphabetical identifiers.
- Test objectives - The specific functional design

features of the valve which are tested by the procedure are stated. For example, "to measure seat leakage of valves ____, ____, and ____."

- Test equipment - The procedure lists each type of test equipment which will be needed for performing measurements required by the procedure.
- Prerequisites - This section of the test procedure lists each prerequisite condition which must be established in order to perform the test. For example, prerequisite positioning of valves, availability of power sources, installation of temporary blanks on system openings, and availability of other systems necessary for supporting the test.
- Limitations - this section of the test procedure identifies any limitations applicable to the test as an entity. For example, system temperature may be required to be above a stated minimum or the test may not be permissible if fuel is loaded.
- Procedure, notes, and cautions - This section of the test procedure states step-by-step instructions for performing the test, measuring test parameters and recording results. The first steps typically require verification of compliance with prerequisites and limitations. It then proceeds with steps in the correct sequence for performing the test. Notes are added as necessary to provide supplementary information to the tester. For example, "Note: the next step energizes the motor actuator to close the valve." Cautions are added as necessary for safety considerations. For example, "Caution: the next step places total reliance on the check valve for preventing reverse flow. As the stop valve is opened during the next step, observe system pressure. If pressure decreases, promptly close the stop

valve and report conditions to the test supervisor." Notes and cautions, when used, are placed immediately prior to the procedural step to which they apply.

- Acceptance criteria - This section of the test procedure states the specific acceptance criteria for the test. Test results are compared to these criteria to determine if the valves have demonstrated acceptable functioning. Sometimes, measurements made during testing require further engineering calculations in order to permit comparison with acceptance criteria.

EXERCISES

The following exercises serve to reinforce the material presented in this module.

1. Using the sample valves as described in the Procedures section of this module, dismantle each valve and sketch its construction. With each sketch include a brief discussion and where it may be typically used as indicated in the Data Table section of this module.

2. Name the parts of a valve which are typically pressure boundary parts.

3. State if the relative pressure loss across the following valves is high or low with the valve fully open and explain why.
   a. gate valve

   b. globe valve

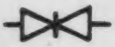
   c. swing check valve

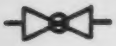
   d. lift check valve

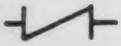
   e. butterfly valve

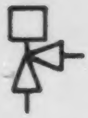
4. Explain how fluid flow affects ease of operating a globe valve.

5. **Name the type of valve represented by:**

a. 

b. 

c. 

d. 

6. **Name items of information about a valve which are identified by the name plate of that valve.**

7. State the general purpose of checking the following during preinstallation inspection:
   a. valve identity
   b. procedures and drawings
   c. prerequisites
   d. valve physical condition
   e. site conditions

8. State the general purpose of checking the following during installation inspection:
   a. control of revisions to procedures and drawings

   b. indication of quality status.

c. compliance with sequence

d. control of nonconformance

e. nondestructive examinations

f. torquing

g. final installation

9. Describe the role of an installation job package.

10. State the purpose of each of the following tests of valves:
    a. operability

    b. hydrostatic

    c. seat leakage

    d. stroke time

    e. relief set point

    f. control system test

11. Name four areas of a valve which are examined for leaks during hydrostatic testing.

12. Briefly describe the performance of check valve functional tests for check valves in pump discharge lines for parallel centrifugal pumps.

13. Briefly describe the performance of a seat leakage test on a stop valve.

14. Briefly describe the performance of a stroke time test of a power actuated valve.

15. Briefly describe the performance of solenoid-pilot actuated relief valve set point test using a thermocouple for temperature measurement in the relief discharge line.

16. Briefly describe the performance of a functional test of a control system which provides for automatic closure of a valve upon system pressure decreasing below 500 psi.

17. Name six sections of a test procedure and generally describe the information provided by each.
a.

b.

c.

d.

e.

f.

MATERIALS

The following valves are suggested for student/trainee use in carrying out the Exercises for this module.

1. Gate Valve
2. Globe Valve
3. Check Valve
4. Plug Valve
5. Butterfly Valve
6. Relief Valve

PROCEDURES

1. Using sample valves of the following types:
    - a. Gate Valve
    - b. Globe Valve
    - c. Check Valve
    - d. Plug Valve
    - e. Butterfly Valve
    - and f. Relief Valve,

    dismantle each valve available.

2. Draw a basic sketch of the construction of each valve in Table 30-3-1.

3. With each sketch, in Table 30-3-2:
    - a. State the primary function of each valve.
    - b. Give an example of where that particular valve could be used.

4. Re-assemble each valve.

DATA TABLE

Table 30-3-1

Sketch of Valve

Valve Type ______________

Valve Condition ________

Date Inspected _________

Table 30-3-2

Valve Data

Valve Type	
Valve Condition	
Date Inspected	
Primary Function	
Typical use of this valve	
Remarks	

REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Section III, The American Society of Mechanical Engineers, New York, N.Y., 1978

ASME, Supplementary Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems for the Construction Phase of Nuclear Power Plants, ANSI - N45.2.8, The American Society of Mechanical Engineers, New York, N.Y., 1975

ASME, Administrative Controls and Quality Assurance for the Operational Phase of Nuclear Power Plants, ANSI N18.7, The American Society of Mechanical Engineers, New York, N.Y., 1976

ASME, Performance Test Code - Safety and Relief Valves, PTC-25.3, The American Society of Mechanical Engineers, New York, N.Y., 1976

Lyons, Jerry L. and Askland, Carl L., Lyon's Encyclopedia of Valves, Van Nostrand Reinhold, 1975

Schweitzer, Philip A., A Handbook of Valves, Industrial Press, 1972

TEST

A. Answer the following questions as either true or false:

____ 1. Pressure boundary parts of valves are bonnet, body, disk, and bonnet-to-body closure mechanism which may be bolts, threaded union, or welded joint.

____ 2. Check valves are used as stop valves due to their low pressure loss when open. They have low seat leakage characteristics although low differential pressure across the disk may result in relatively high seat leakage. They have poor throttling characteristics. Actuators must overcome friction from differential pressure across the disk.

____ 3. Globe valves may be used as stop valves if their relatively high pressure loss when open is not a major concern. They have good throttling characteristics for use in flow regulation. They have very low seat leakage rates. The valve may be arranged where fluid flow aids opening and impedes closing or vice versa.

____ 4. Check valves permit flow from inlet to outlet but not vice versa. Styles include swing check, lift check, and stop lift check. Swing checks have lowest pressure loss when open. Stop lift checks also function as a stop valve. Lift checks and stop lift checks typically have less reverse flow seat leakage than swing checks.

____ 5. Plug valves and ball valves are used as stop valves. They have low pressure loss when open and low seat leakage when closed.

____ 6. Butterfly valves are used as stop vales and throttle valves. They have high pressure loss when open and, provided the resilient seats are in good condition, they have low seat leakage when closed. They are typically used in high pressure, large piping systems.

____ 7. Relief valves and safety valves provide protection from overpressurization and may be pilot actuated or self actuated. Relief valves are used to protect liquid systems and safety valves are used to protect liquid systems and safety valves are used to protect gas systems. The pressure at which the valve is set point pressure.

____ 8. Steam traps drain condensate from steam lines without discharging steam. Thermostatic traps use either bimetallic actuator or bellows containing volatile liquid actuator. Mechanical traps use either ball or bucket floats as actuators.

____ 9. Types of valve actuators include manual handwheel, manual lever, electric motor, pneumatic, cryogenic, pyrotechnic and piezoelectric.

____ 10. Motor actuators use limit switches to secure power to the motor upon full valve closure or opening.

____ 11. Types of valve indications include local and remote. Local indication is typically by mechanical indicator connected to the stem or actuator gear train. Remote indication is typically by a claxon horn.

____ 12. Preinstallation inspection verifies that:
- Valve identity matches that required by the installation job package.
- Approved procedures and drawings are available.
- Qualified personnel are available, as required.
- Prerequisites are met.
- Necessary handling and fixturing equipment are available.
- Safety requirements are met.
- Valves have not been damaged, do not have unresolved nonconformances, and are adequately clean.

- Installation site conditions are adequate for maintaining valve quality.

____ 13. Valve identity is provided by its nameplate which identifies (1) valve manufacturer, (2) types of valve, (3) design pressure and temperature, (4) code classification, (5) valve serial number, and (6) national board number.

____ 14. Installation inspection verifies that:

- Revisions of procedures and drawings are provided to the installation site as appropriate.
- Qualified personnel and approved materials and procedures are used.
- Quality status indication is maintained.
- Specified sequences are met.
- Nonconformances are corrected.
- Required as-built dimensions are recorded.
- Required inspections and tests are performed.
- Required nondestructive examinations are performed.
- Installation work complies with procedural and drawing requirements including those for orientation, torquing, cleaning, welding, pipe fitting, housekeeping, and protection of valve internals.
- All steps of the installation job package have been completed.
- Limit switches, interlocks and stops are installed as required.
- All specified mounts, hangers, and supports are installed as required.
- All specified temporary protective plugs, covers, and strainers are installed.

____ 15. The installation job package contains sequential instructions for installing valves, welding instructions, packing repair procedures and non-destructive examination techniques for the valve.

____ 16. Valve operability tests are performed as one of the final steps of installation. They verify full valve operation by its actuator opening the valve within 3.5 seconds.

____ 17. Hydrostatic tests verify that maximum leakage requirements of installed systems, including valves, are met. Hydrostatic tests are performed by filling and venting the system with water, raising water pressure to test pressure, and visually examining exterior surfaces for leaks. Valve areas examined are stem packing, bonnet-to-body joint, body-to-pipe joints, and external surfaces of the bonnet and body. These tests normally take place at seventeen (17) times the rated system pressure.

____ 18. Check valve functional tests verify that reverse flow does not occur. These tests are performed by establishing a higher pressure on the check valve outlet and observing for reverse flow.

____ 19. Seat leakage tests verify complaince with specified maximum seat leak rates. These tests are performed by establishing a specified differential pressure across the closed valve, collecting leakage for a timed interval, and calculating leak rate.

____ 20. Stroke time tests verify that time of full valve travel is within specified limits. These tests are performed by operating the valve by its normal actuator and measuring the time of full travel to be less than or equal to 3.5 seconds.

____ 21. Relief and safety set point tests verify that relief valves and safety valves open within a specified range of pressure. These tests are performed by actuating the pilot of pilot-operated reliefs and on test stands for self-actuated relief and safety valves.

____ 22. Open-close control system tests verify that controlled valves either open or close as designed at specified values of plant parameters. These tests are performed by simulating plant parameters and observing the value at which the value actuates.

____ 23. Variable position control system tests verify that controlled valves position proportionally to values of plant parameters. These tests are performed by simulating plant parameters and observing for specified positioning of the valve.

____ 24. Written test procedures govern conduct of tests. Each test procedure contains (1) title, number, and revision, (2) test objectives, (3) test equipment, (4) prerequisites, (5) limitations, (6) procedure, notes, and cautions, and (7) acceptance criteria.

____ 25. In the flexible wedge of a parallel disk gate valve, seat leakage is typically lowest when the differential pressure across the closed value is lowest.

B. Answer the following questions as indicated:

1. State the primary functions of:
    a. gate valves
    b. globe vlaves
    c. check valves
    d. plug valves
    e. butterfly valves
    f. relief valves

2. In the flexible wedge of parallel disk gate valve, seat leakage is typically highest when differential pressure across the closed valve is lowest. Explain how this occurs.

3. Describe the operation of a self-actuated, spring loaded relief valve.

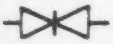
4. State the purpose and describe the operation of a bucket type steam trap.

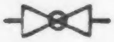
5. Briefly describe the operation of the following valve actuators.
    a. Hammer handwheel

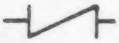
    b. Motor

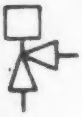
    c. Single solenoid

6. Name the type of valve represented by:

   a. 

   b. 

   c. 

   d. 

7. Name items of information about a valve which are identified by the name plate of that valve.

8. Describe the role of an installation job package.

9. State the purpose of each of the following tests of valves.

   a. operability

   b. hydrostatic

   c. seat leakage

   d. stroke time

   e. relief set point

   f. control system test

10. Name four areas of a valve which are examined for leaks during hydrostatic testing.

11. Name six sections of a test procedure and generally describe the information provided by each.

    a.

    b.

    c.

    d.

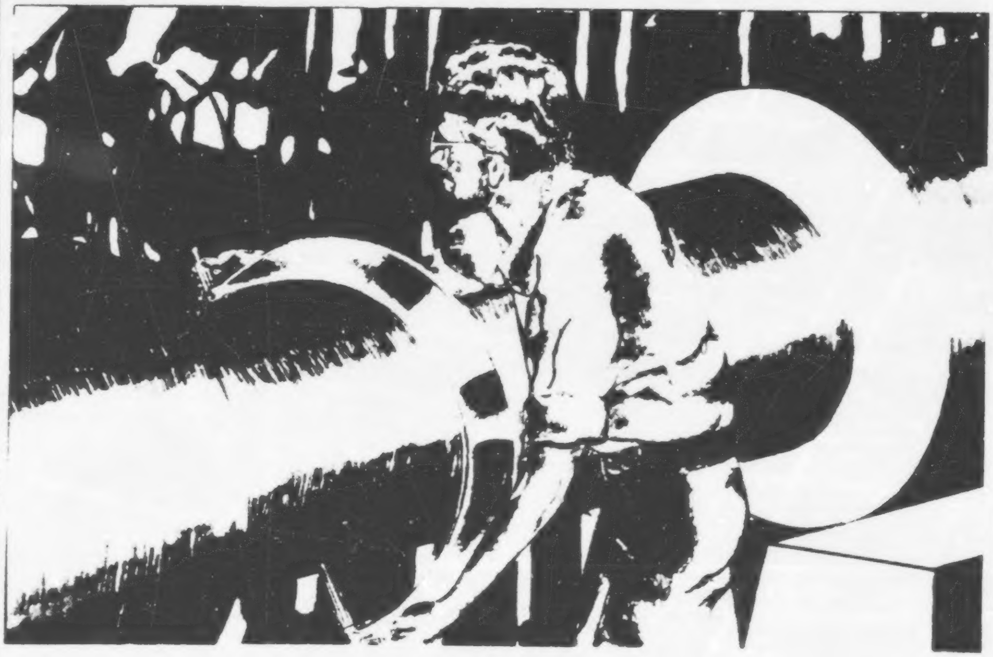
    e.

    f.

NUCLEAR TECHNOLOGY

MODULE 30-4

PIPING INSPECTION



COURSE 30 MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

MODULE 30-1	Pump Inspection
MODULE 30-2	Pump Functional Testing
MODULE 30-3	Valve Inspection
MODULE 30-4	Piping Inspection
MODULE 30-5	Sufrace Cleaning Inspection
MODULE 30-6	Protective Coating Inspection
MODULE 30-7	Pressure Vessel Inspection
MODULE 30-8	Rotating Equipment Inspection

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INTRODUCTION

The Nuclear QA/QC Technician assigned to verify installation or modification of piping systems performs a variety of checks to determine compliance with specification, drawings, and procedures. The variety of pipe and fittings requires the ability to recognize specified types including methods of connection. The Technician commences verifications at the time of assembly of materials and completes verifications after the piping system is installed. The specific checks made and the frequency of such checks varies with the importance of the system to safe plant operation.

This module introduces the classifications of pipe and fittings and the types of connections used in the installation of piping systems. Typical marking schemes are described and the basic purposes of fittings are illustrated. Subsequently, this module describes the preinstallation and installation verifications which typically apply to piping systems. Finally, tests of the completed installation are enumerated.

MODULE PREREQUISITES

There are no prerequisites for this module.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Name and recognize classifications of pipe and fittings.
2. Match styles of fittings with their function.
3. Recognize pipe and fitting identification schemes and name the types of information identified by typical schemes.
4. Differentiate between permanent and nonpermanent piping connections and describe examples of each type.
5. State the general purpose of piping preinstallation verifications and describe typical verifications.
6. State the general purpose of piping installation verifications and describe typical verifications.
7. Describe the use of records of piping installation and verification including QC Inspection Report, Nonconformance Report, Deficiency Report, and ASME Code Form N-5.
8. State the purpose of flushing and hydrostatic testing and describe principle sources of leakage during hydrostatic testing.

TYPES OF PIPING, FITTINGS, AND CONNECTIONS

Pipe Classifications

The basic definition of pipe is "a tube, usually cylindrical, used for conveying a fluid or transmitting fluid pressure and normally designated as " pipe " in the applicable specification." Piping is classified by two distinct categories: (1) Seam constructed and (2) seamless. Pipe is further classified under these two broad categories by the manufacturing process used to fabricate the pipe.

Seam constructed pipe is fabricated by one of six methods of manufacture. These methods are as follows; Figures 30-4-1 and 30-4-2 illustrate two popular methods:

- Electric Resistance Welded Pipe (longitudinal butt welding with direct current)
- Furnace Butt Welded Pipe Bell Welded (longitudinal butt welding by forging and mechanical pressure)
- Furnace Butt Welded Pipe-Continuous Welded (longitudinal butt welding by forging and mechanical pressure)
- Electric Fusion Welded Pipe (longitudinal butt weld by electric arc welding)
- Electric Flash Welded Pipe (longitudinal butt weld entire length simultaneously via resistance to current)
- Double Submerged Arc Welded Piping (longitudinal butt weld, submerged arc, at least two passes).

Seamless pipe is fabricated by one of five distinct manufactured methods as follows; Figures 30-4-3 and 30-4-4 illustrate two popular methods:

- Rolled Pipe (Forged billet, pierced by a conical mandrel between two diametrically opposed rolls)

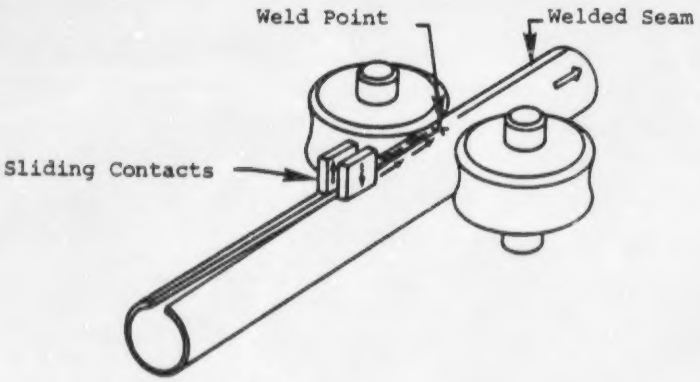


Figure 30-4-1. Electrical Resistance Weld Pipe

- Forged or Bored Piping (Produced by boring or trepanning of a forged billet)
- Extruded Pipe (Produced from hollow or solid round forgings, usually in a hydraulic extrusion press)
- Centrifugally Cast Pipe (formed from the solidification of molten metal in a rotating mold)
- Statically Cast Pipe (Formed by the solidification of molten metal in a sand mold)

Piping Fittings

Forged or wrought fittings are used to connect pipe. Fittings are classified as (1) weld and (2) bolted flange, or (3) compression. They are further classified by shape and purpose. These categories are illustrated in Figures 30-4-5 through 30-4-9.

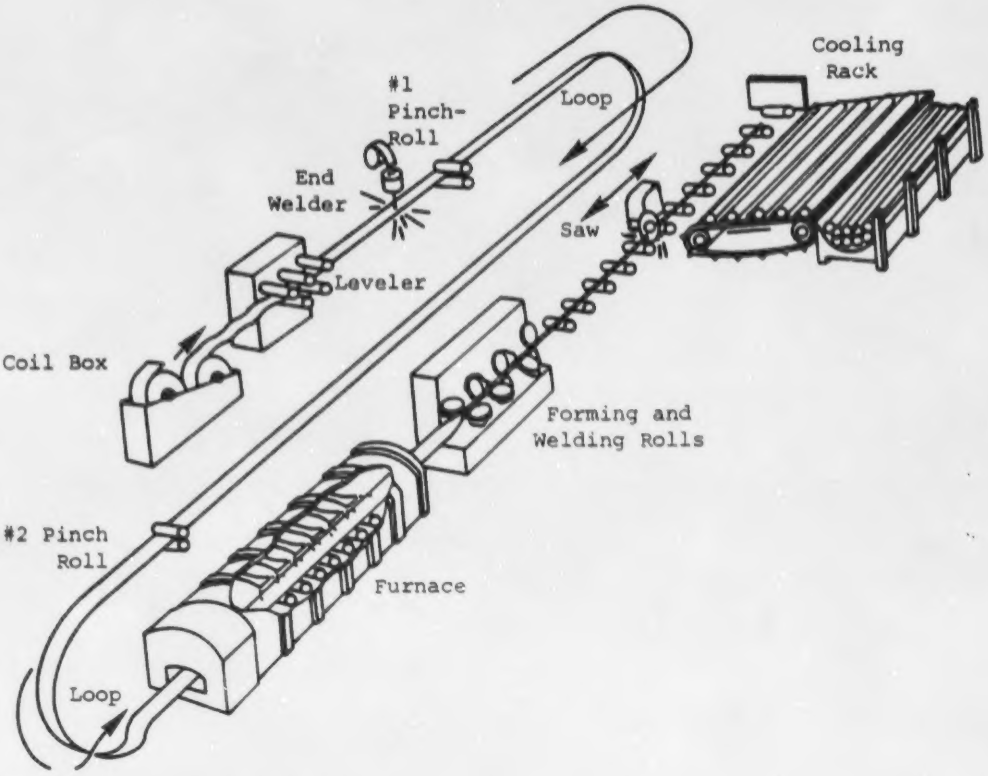

Cooling
Rack
#1
Pinch-
Roll
Loop
End
Welder
Saw
Leveler
Coil Box
Forming and
Welding Rolls
#2 Pinch
Roll
Furnace
Loop

Figure 30-4-2. Furnace Butt Welding Pipe, Continuous Process (The Yoder Mill Method)

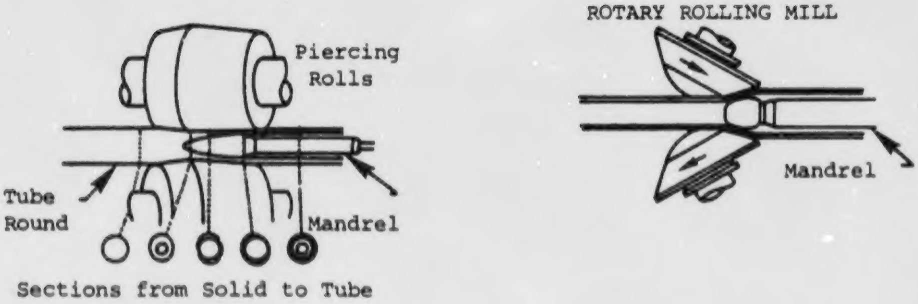
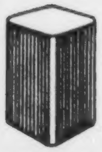
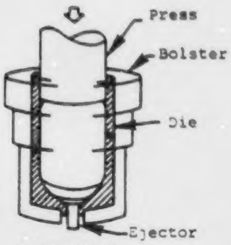

Piercing Rolls
Tube Round
Mandrel
Sections from Solid to Tube
ROTARY ROLLING MILL
Mandrel

Figure 30-4-3. Rolled Pipe



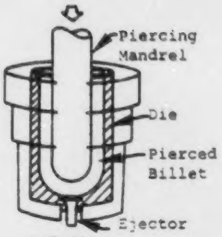
HEATING THE BILLET

A solid steel billet, already worked in rolling from an ingot, is heated to forging temperature.


Press
Bolster
Die
Ejector

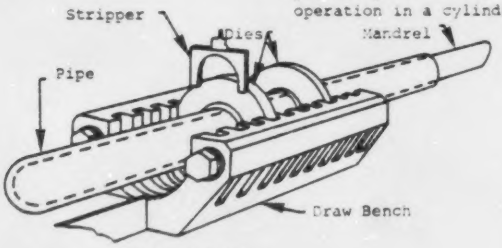
PREFORMING

In this initial forming operation, the heated billet is pressed and partially formed for the piercing operation in a cylindrical "die pot".


Piercing Mandrel
Die
Pierced Billet
Ejector

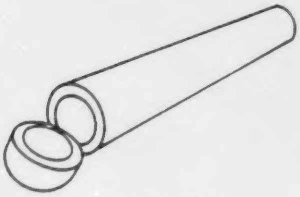
PIERCING

The billet, formed to fit snugly in the die pot, is pressed into a closed-end bellow forging by a piercing mandrel in a vertical press.


Stripper
Dies
Mandrel
Pipe
Draw Bench

HEAT AND DRAW

The forging is pushed through a series of circular dies by a mandrel inserted in the open end. Multiple "draws" are made to reduce the wall thickness and diameter and increase the length.



FINISHING

The closed end may then be retained or removed depending on product application.

Figure 30-4-4. Drawn Pipe

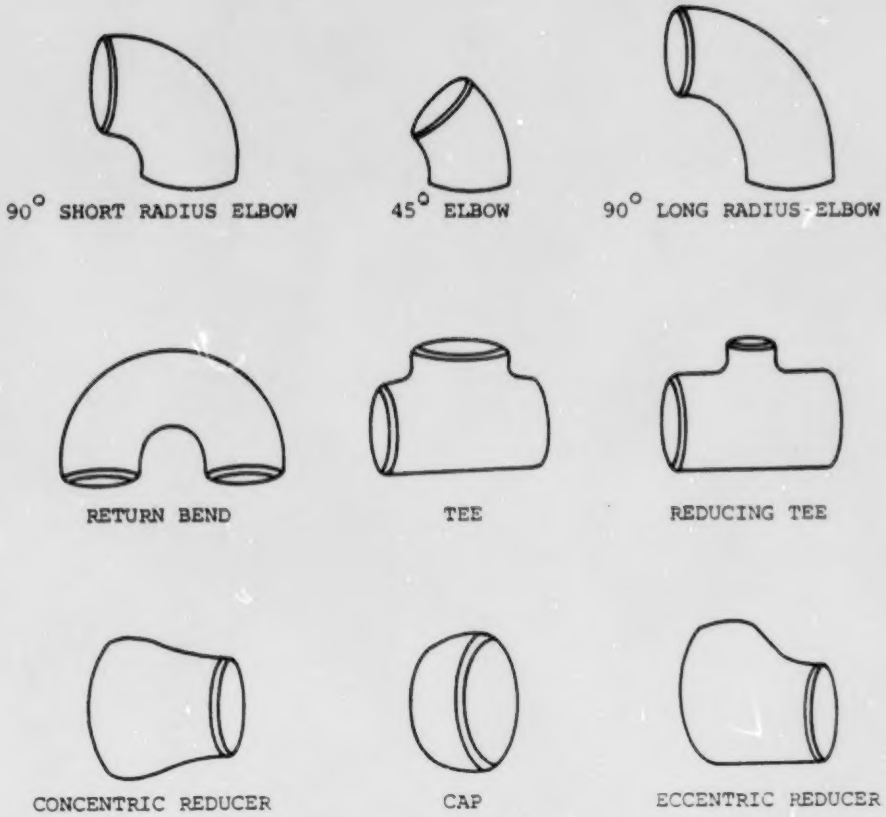

90° SHORT RADIUS ELBOW
45° ELBOW
90° LONG RADIUS ELBOW
RETURN BEND
TEE
REDUCING TEE
CONCENTRIC REDUCER
CAP
ECCENTRIC REDUCER

Figure 30-4-5. Weld End Fittings

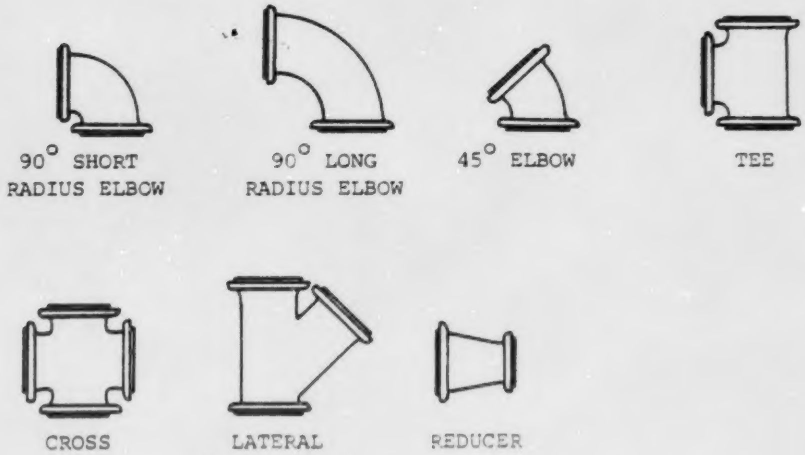

90° SHORT RADIUS ELBOW
90° LONG RADIUS ELBOW
45° ELBOW
TEE
CROSS
LATERAL
REDUCER

Figure 30-4-6 Cast Bolted Flange Fittings

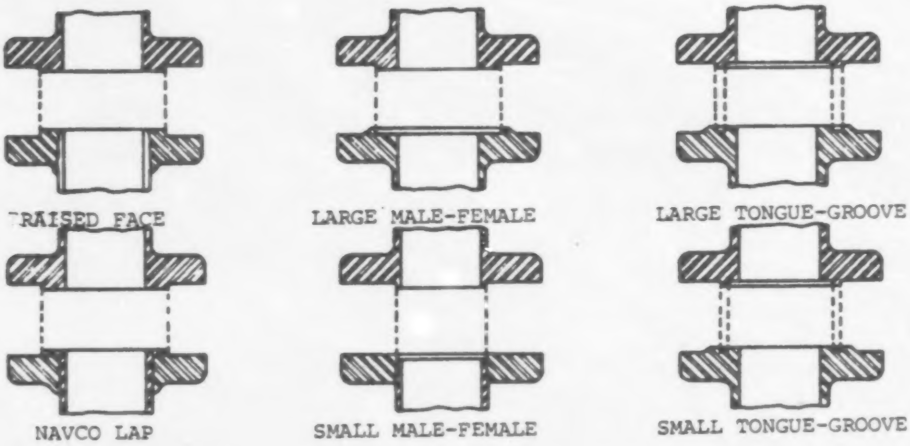

RAISED FACE
LARGE MALE-FEMALE
LARGE TONGUE-GROOVE
NAVCO LAP
SMALL MALE-FEMALE
SMALL TONGUE-GROOVE

Figure 30-4-7. American Standard Bolted Flange Facings

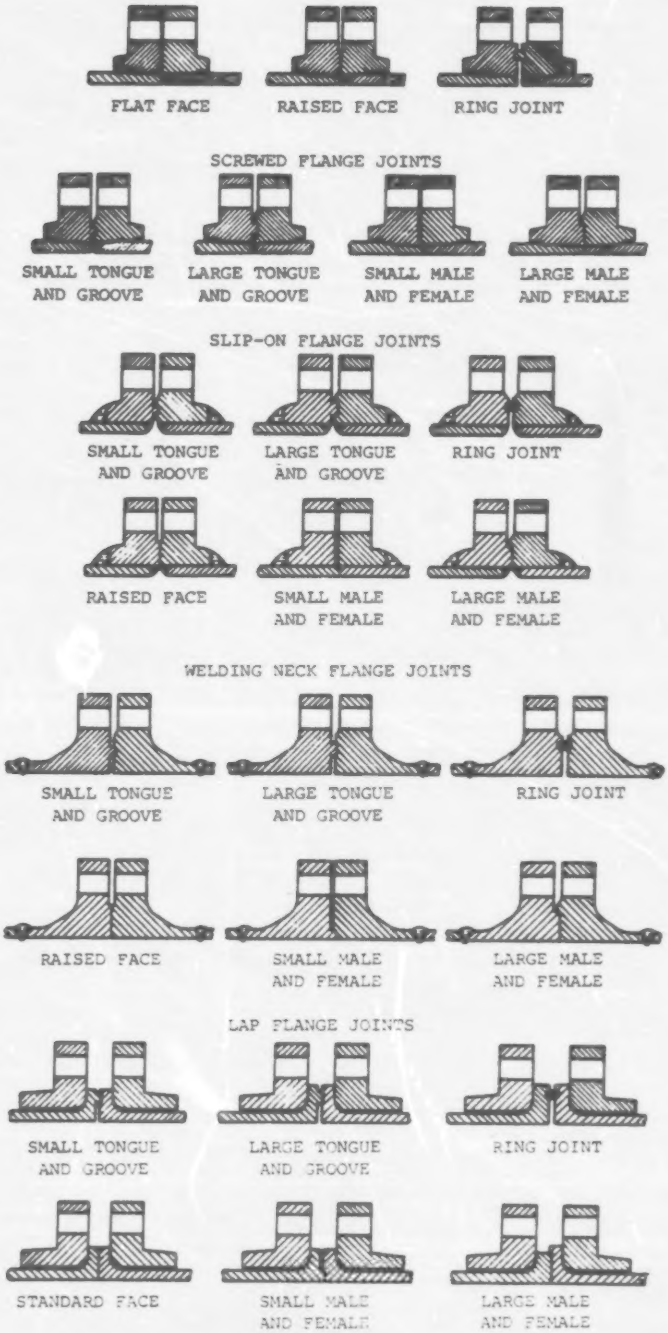

FLAT FACE
RAISED FACE
RING JOINT
SCREWED FLANGE JOINTS
SMALL TONGUE AND GROOVE
LARGE TONGUE AND GROOVE
SMALL MALE AND FEMALE
LARGE MALE AND FEMALE
SLIP-ON FLANGE JOINTS
SMALL TONGUE AND GROOVE
LARGE TONGUE AND GROOVE
RING JOINT
RAISED FACE
SMALL MALE AND FEMALE
LARGE MALE AND FEMALE
WELDING NECK FLANGE JOINTS
SMALL TONGUE AND GROOVE
LARGE TONGUE AND GROOVE
RING JOINT
RAISED FACE
SMALL MALE AND FEMALE
LARGE MALE AND FEMALE
LAP FLANGE JOINTS
SMALL TONGUE AND GROOVE
LARGE TONGUE AND GROOVE
RING JOINT
STANDARD FACE
SMALL MALE AND FEMALE
LARGE MALE AND FEMALE

Figure 30-4-8. Bolted Flange Joints

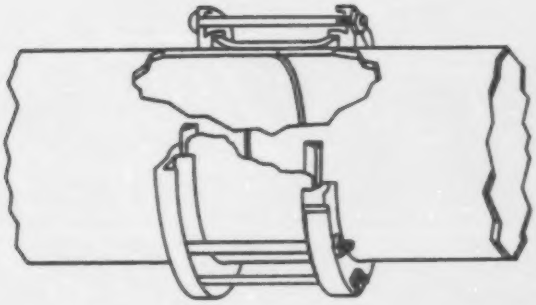


Figure 30-4-9. Compression Sleeve Mechanical Coupling

Identification of Piping and Fittings

Piping and fittings are manufactured in conformance with the various ASME, ASTM or API specifications. Each pipe and fitting is marked by the manufacturer in accordance with the appropriate specification. There are various methods of affixing the markings along with limitiations. The two common practices are diestamping and stenciling. Special requirements apply to both methods to ensure that the marking process does not adversely affect the quality of the pipe. For example, limits are placed on the radius of die stamps to minimize stress concentrations. Stenciling ink must not contain elements which are deleterious to the material. For example, lead is prohibited for stainless steels and inconels. Also, small diameter piping usually found in bundles is marked with a tag attached to the bundle versus individual pipe marking.

Based upon the "Simplified Practices Recommendations R247, Packing, Marking and Loading Methods for Steel Products for Domestic Shipments" which is published by the United States Department of Commerce, and the applicable piping standards, pipe markings generally identify:

- Name or Brand of Manufacture
- Size

- Grade
- Length
- Weight per foot
- Classification of pipe (manufacture process)
- Type of material
- Specification for manufacturing.

Figures 30-4-10 and 30-4-11 illustrate two methods of markings for similar pipe. While similarities exist in these two methods, it is apparent that on-the-job inspection must refer to the specific piping code to determine the exact marking required.

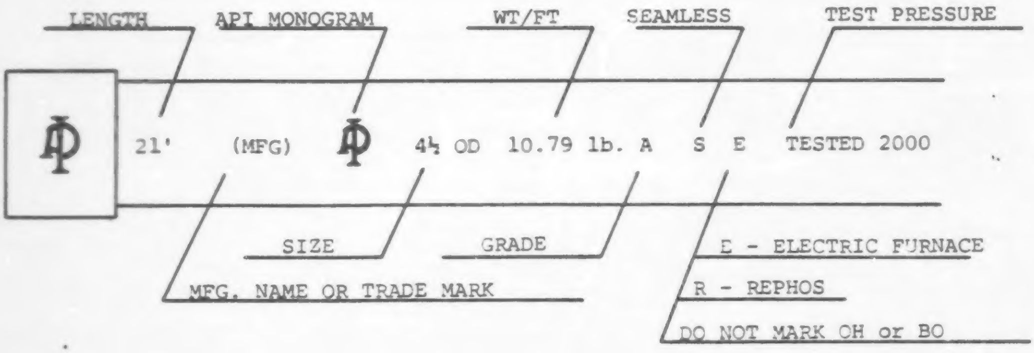

LENGTH
API MONOGRAM
WT/FT
SEAMLESS
TEST PRESSURE
21'
(MFG)
4½ OD
10.79 lb.
A
S
E
TESTED 2000
SIZE
GRADE
E - ELECTRIC FURNACE
R - REPHOS
MFG. NAME OR TRADE MARK
DO NOT MARK OH or BO

Figure 30-4-10. API Line Pipe 2" and Over

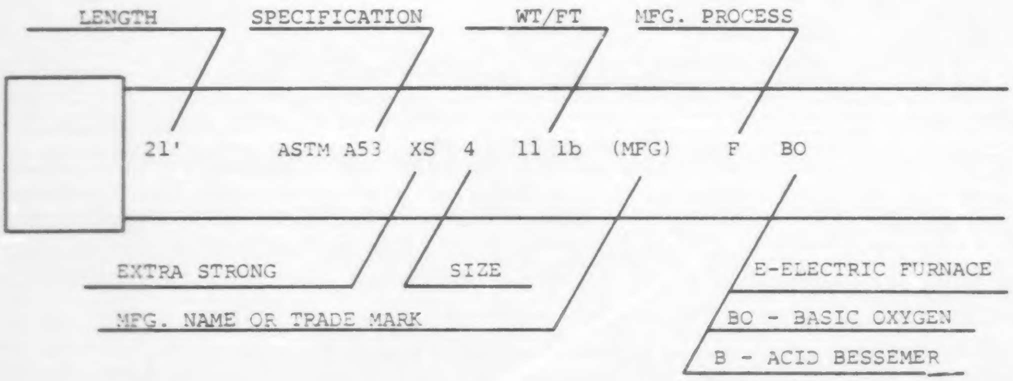

LENGTH
SPECIFICATION
WT/FT
MFG. PROCESS
21'
ASTM A53
XS
4
11 lb
(MFG)
F
BO
EXTRA STRONG
SIZE
E-ELECTRIC FURNACE
MFG. NAME OR TRADE MARK
BO - BASIC OXYGEN
B - ACID BESSEMER

Figure 30-4-11. ASTM A-53 Size 2" and Over

Piping Connections

Piping connections are either permanent of nonpermanent. Permanent connections are those which are welded. Nonpermanent connections are designed for easy disassembly and reassembly. These are comprized of connections by bolted flange, threaded union, and compression sleeve mechanical connection.

Permanent connections are made by a welding process which fuses the two metal pieces. The weld joint used for welded connection is either the butt weld or the socket weld.

As illustrated in Figure 30-4-12, the butt weld joint consists of physically butting the piping ends together. Depending upon the system/piping specification, a backing ring may or may not be used. Where backing rings are not used, a consumable insert may be required for the butt joint. In either case, inspection of butt joints verifies that (1) the ends have been finished per drawing requirements, (2) surfaces are clean and free of paint, oil, rust, scale, or other material, (3) alignment and root openings are accurate within drawing tolerances, (4) alignment is preserved during welding, and (5) the correct weld process is used per the installation specifications.

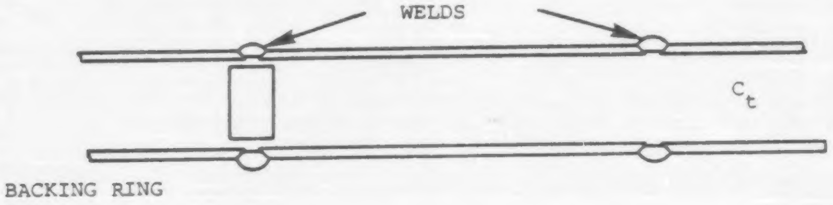


Figure 30-4-12. Butt Welds, With and Without Backing

The first three items for inspection of butt welds apply to inspection of socket welds. In addition, the fit between the socket and the pipe is verified to comply with the installation specification. Figure 30-4-13 illustrates a typical socket weld which is common in power plants.

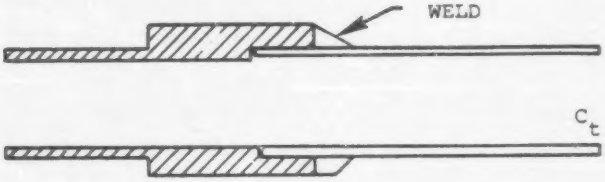


Figure 30-4-13. Socket Weld

Nonpermanent connections vary in complexity and application and their use is dependent upon the design specification for the piping system. The types which usually appear in power plants are:

- Threaded Pipe Joints
- Flanged
- Solder
- Caulked
- Flared/Nonflared Compression Fitting
- Compression Sleeve.

Flanged connections are illustrated by previous Figures 30-4-7 and 30-4-8. Flanged connections exist in many styles, but all require bolting and usually gasket material. The specific design of the flange faces is stipulated by the system piping specification. Gasket material when specified, must be such that it is neither affected by the fluid at operating temperatures nor releases undesired elements into the fluid. Metallic or asbestos-metallic gaskets are used on flat or raised face flanges when fluid operating pressure is high (greater than 720 psi). The bolting for the flange conforms to applicable

American National Standard specifications. Course threads are normally used and washers, nuts and bolts are of the same material.

The Compression Sleeve Coupling illustrated in Figure 30-4-9 relies upon the compression of each of the rubber wedge gaskets to seal each end of the coupling against the pipe and the conically flared middle section. The bolting exerts the required pressure. The resultant joint is flexible and leak-proof.

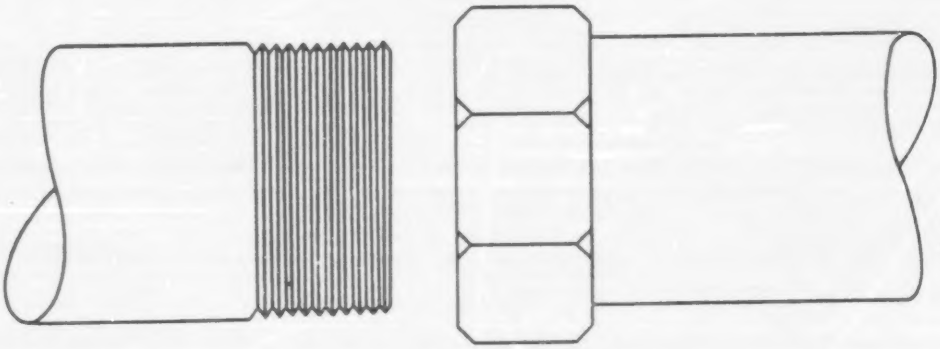


Figure 30-4-14. Threaded Connection

Many threaded pipe joints are tapered threads to provide for tight sealing of the joint. For non-tapered thread connections, a seal weld or a sealing surface other than the threads is used to prevent joint leakage. Limitations on the use of threaded joints include their susceptability to erosion, corrosion, and shock or vibration damage.

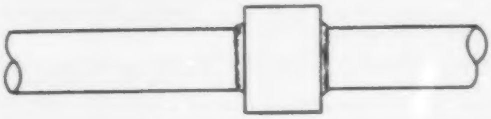


Figure 30-4-15. Soldered Connection

Solder connections are rarely used in power systems but can be found in such systems as low pressure cooling water, potable water, and fire water systems. In almost all cases a socket connection is used with either end-fed brazing material or preinserted rings. Soldered connections which are connected solely by a fillet are unacceptable.

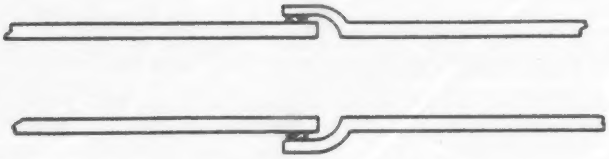


Figure 30-4-16. Caulked Connection

Caulked or lead filled piping connections use the bell and spigot type joint. These are primarily found in cold water service systems. This type of joint or connection has many limitations. If it is intended to be used at pressure, the bends, laterals, and dead ends require lateral support to prevent disengagement.

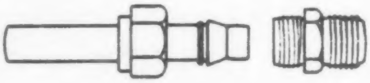


Figure 30-4-17. Flared Fitting

Flared and flareless compression fittings are mostly found in piping runs under 2 inches outside diameter. Instrumentation lines make considerable use of these connections. The compression fitting uses threaded couplers to compress a ferrule or to exert pressure on flared pipe ends by a tapered insert.

INSPECTIONS DURING CONSTRUCTION AND MODIFICATION

Pre-Installation Verification

The pre-installation verification task for a QA/QC Technician begins after a piping run has been scheduled for installation and the materials to be used have been collected by the contractor. It is assumed that receipt inspections were previously completed and personnel assigned to the construction or modification job are "qualified". The role of the QA/QC Technician for this job usually consists of observation and reporting. Of course this will depend upon the character of the QA/QC Department and the particular job requirements.

Preinstallation verifications determine that materials, software, and job conditions are suitable to commence the installation or modification work. Items subject to pre-installation verification are:

- materials are present and of correct type as specified by the job specification and drawings.
- adjacent activities do not adversely effect the job.
- materials are protected from inclement weather.
- specifications, drawings, and instructions are at the job site and approved for use.
- clean areas are established if so required by the job specification.
- installation and inspection check lists, if required, are present and approved for use.

Installation Verification

During installation activities, the Nuclear QA/QC Technician's involvement ranges from "spot checks" to full time verification of installation steps. These verifications may be on a surveillance basis or specific "hold points" may be established where inspections must be performed prior to work proceeding past such hold points. The complexity of the job and the importance of the piping system to plant safety determines the extent of verifications.

Installation verifications determine that installation processes and the installed piping system comply with applicable specifications, drawings and procedures. Items subject to installation verifications are:

- compliance with procedures such as welding, brazing, and soldering procedures.
- cleanness of components
- protection of components from damage from handling, fixturing, and installing
- accomplishment of inspection hold points, as applicable
- nondestructive examinations of welds and solder joints
- calibration of measuring and test equipment
- completeness of installation including gaskets, bolting, supports and hangers.
- completion of records.

QA Records

Quality assurance programs require the documentation of QA/QC inspections, tests and surveillance. The QC Inspection Report illustrated by Figure 30-4-18 is a typical format for documenting preinstallation and installation verifications.

As illustrated in Figure 30-4-18, the QA Inspection Report is adaptable to any inspection or verification. In the event a nonconformance is identified, a separate report similar to that in Figure 30-4-19 is issued. Use of a separate report for nonconformances permits convenient review and disposition by responsible departments.

QUALITY CONTROL INSPECTION REPORT 1.0 QCTR. NO:______________

2.0	SITE LOCATION: ______________	6.0	WR OR MOD NO: ______________
3.0	SYSTEM NAME/NO. ______________	7.0	CLASS I II III
3.1	COMPONENT NAME/NO. ______________	8.0	MATERIAL REPLACEMENT REQUIRED__________
4.0	RESPONSIBLE DEPT/GROUP ________	8.1	MATERIAL CERTIFICATION REQUIRED _______
5.0	ACTIVITY LOCATION ______________	8.2	MATERIAL PURCHASE ORDER NO. __________

9.0 PROCEDURE TITLE/NO. ____

10.0 PREREQUISITES ACCOMPLISHED YES ____ NO____ (IF NO, EXPLAIN UNDER REMARKS)

11.0 REASONS FOR ACTIVITY:

12.0 WORK DESCRIPTION (INCLUDE MATERIAL AND COMPONENTS USED):

13.0 RETEST REQUIREMENTS:

14.0 TESTS PERFORMED:

15.0 TEST DATA:

16.0 REMARKS:

17.0 QC INSPECTOR ________________________ DATE/TIME ________________________

Figure 30-4-18. Sample Inspection Report

Nonconformances denote a material or component condition which violates specification or drawing requirements. In addition to nonconformances, other problems may be identified such as violations of procedural requirements. Such violations are typically termed "deficiency" or "noncompliance" and are separately reported. A sample deficiency report form is illustrated in Figure 30-4-20. The form permits addition of corrective action by the responsible contractor to rectify the deficiency and to prevent its reoccurrence.

Many of the piping systems of a nuclear power plant are subject to the provisions of the ASME Boiler and Pressure Vessel Code (Code). In such cases, the Code requires the completion of a "Data Report for Field Installation of Nuclear Power Plant Components, Component Supports, and Appurtenances." This report is numbered "N-5" and is illustrated in Figure 30-4-21.

The N-5 form provides for recording the specific items which are installed to comprize a system and for certifying compliance of such items with the Code. It includes pumps, valves, and piping assemblies and it lists the specifications, drawings and procedures complied with by the installation process. The QA/QC verifications of preinstallation and installation activities serve as a basis for the owner's acceptance of the N-5 report.

QUALITY CONTROL NONCONFORMANCE REPORT (NCR)

Site Location: ______________________ Report No. __________

Date ______________

Component Identification ______________ System # ____________

Purchase Order # ______________ Specification # ______________

Supplier/Contractor ______________________ Dwg. # __________

Inspected by ______________________ Hold/Reject

Approved by ______________________ Tag # ______________

QC Supervisor

Item Description of Nonconforming Material

Recommended Action:

Accept As Is ___ Scrap ___ Rework ___ Return ___

Corrective Action/

Preventative Action: ____

____

____

____

By: ______________ ________

Date

Response Accepted By: ______________ ________

Date

Reowrk Complete	Rework Inspected	Nonconformity Closed
	Accepted ______	
	Unaccepted ____	______________
By __________	By __________	QC Supervisor
Date __________	Date __________	Date ______________

Figure 30-4-19. Sample Nonconformance Report

DEFICIENCY AND CORRECTIVE ACTION REPORT

Report No.______

Need for Corrective Action:

Date ___________

Failure ______

Malfunction ______

Deficiency ______

Deviation ______

Defective Equipment ______

APPROVED BY: ____________________
QC SUPERVISOR

HOLD/REJECT
TAG # ____________________________

Component Identification ____________________

System No. ______

Purchase Order No. ____________________

Spec. No. ______

Supplier/Contractor ____________________

Drawing No. _____

Corrective Action Requested of ____

Description of Condition:

Cause of Condition:

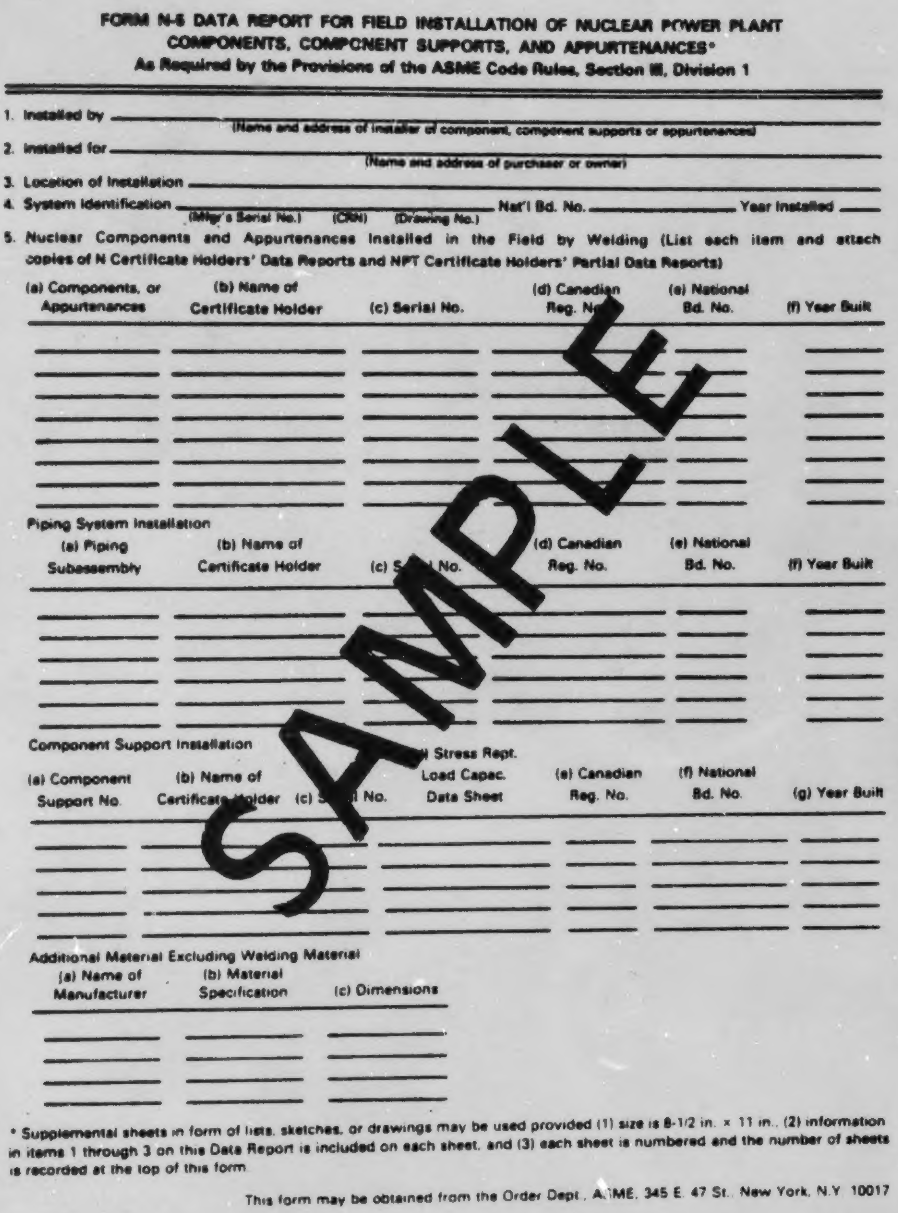
CORRECTIVE ACTION/
PREVENTIVE ACTION:

By: _______________ _______________
Date

Response Accepted By: _______________ _______________
QC Supervisor Date

Implementation
Verfied By:

Figure 30-4-20. Sample Deficiency Report



FORM N-5 DATA REPORT FOR FIELD INSTALLATION OF NUCLEAR POWER PLANT COMPONENTS, COMPONENT SUPPORTS, AND APPURTENANCES*

As Required by the Provisions of the ASME Code Rules, Section III, Division 1

1. Installed by ______________________________ (Name and address of installer of component, component supports or appurtenances)
2. Installed for ______________________________ (Name and address of purchaser or owner)
3. Location of Installation ______________________________
4. System Identification ______________________________ (Mfgr's Serial No.) (CRN) (Drawing No.) Nat'l Bd. No. ______________ Year Installed ______
5. Nuclear Components and Appurtenances Installed in the Field by Welding (List each item and attach copies of N Certificate Holders' Data Reports and NPT Certificate Holders' Partial Data Reports)

(a) Components, or Appurtenances	(b) Name of Certificate Holder	(c) Serial No.	(d) Canadian Reg. No.	(e) National Bd. No.	(f) Year Built

Piping System Installation

(a) Piping Subassembly	(b) Name of Certificate Holder	(c) Serial No.	(d) Canadian Reg. No.	(e) National Bd. No.	(f) Year Built

Component Support Installation

(a) Component Support No.	(b) Name of Certificate Holder	(c) Serial No.	(d) Stress Rept. Load Capac. Data Sheet	(e) Canadian Reg. No.	(f) National Bd. No.	(g) Year Built

Additional Material Excluding Welding Material

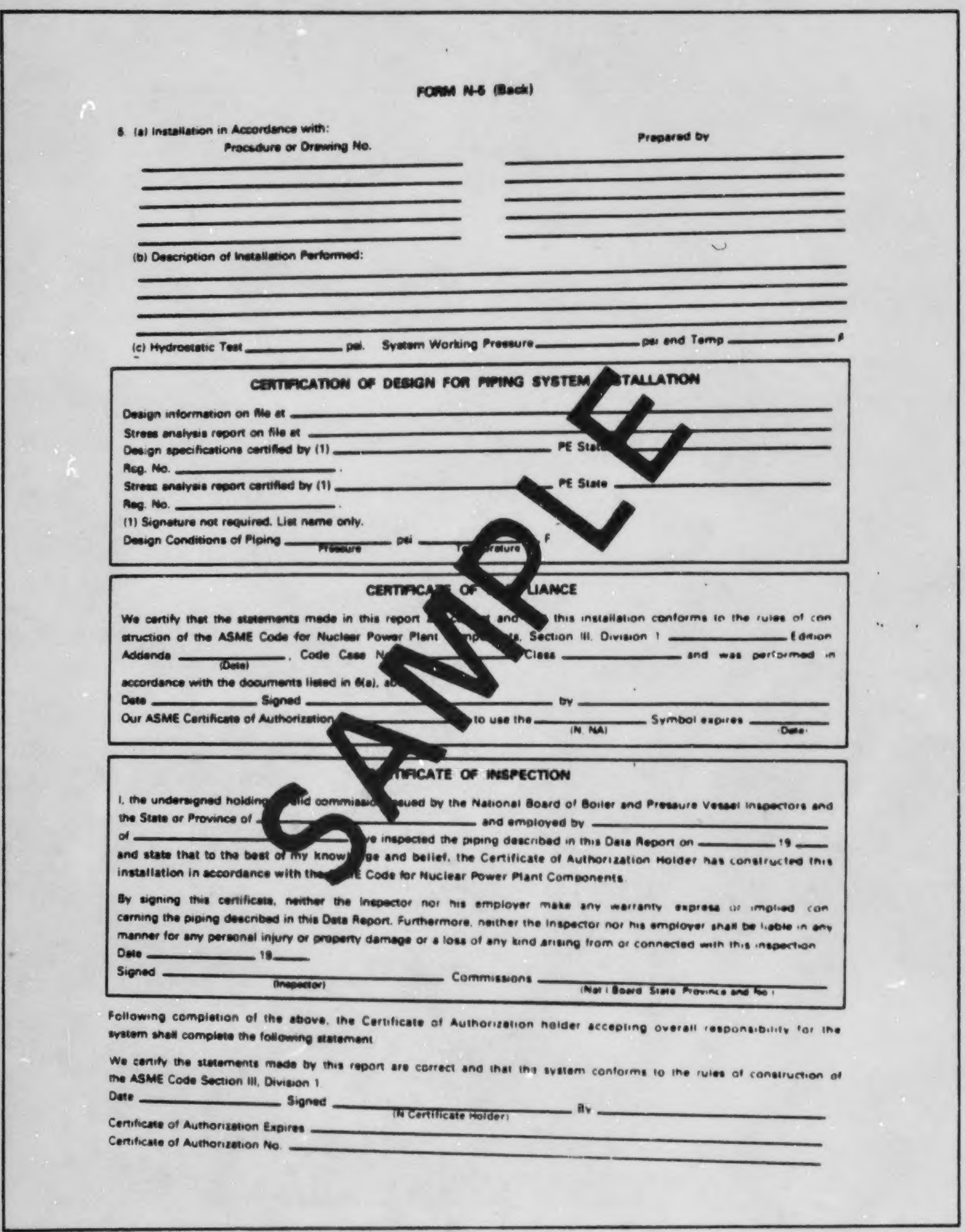
(a) Name of Manufacturer	(b) Material Specification	(c) Dimensions

SAMPLE

* Supplemental sheets in form of lists, sketches, or drawings may be used provided (1) size is 8-1/2 in. × 11 in., (2) information in items 1 through 3 on this Data Report is included on each sheet, and (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

This form may be obtained from the Order Dept., ASME, 345 E. 47 St., New York, N.Y. 10017

Figure 30-4-21A. ASME N-5 Form



FORM N-5 (Back)

5. (a) Installation in Accordance with:
Procedure or Drawing No. ____ Prepared by ____

(b) Description of Installation Performed: ____

(c) Hydrostatic Test ____ psi. System Working Pressure ____ psi and Temp ____ F

CERTIFICATION OF DESIGN FOR PIPING SYSTEM [illegible]STALLATION

Design information on file at ____
Stress analysis report on file at ____
Design specifications certified by (1) ____ PE Stat[illegible] ____
Reg. No. ____ .
Stress analysis report certified by (1) ____ PE State ____
Reg. No. ____ .
(1) Signature not required. List name only.
Design Conditions of Piping ____ (Pressure) psi ____ (Te[illegible]rature) F

CERTIFICA[illegible] OF [illegible]LIANCE

We certify that the statements made in this report [illegible] and [illegible] this installation conforms to the rules of construction of the ASME Code for Nuclear Power Plant [illegible]mpo[illegible]ts, Section III, Division 1 ____ Edition
Addenda ____ (Date), Code Case N[illegible] Class ____ and was performed in accordance with the documents listed in 6(a), ab[illegible]
Date ____ Signed ____ by ____
Our ASME Certificate of Authorization [illegible] to use the ____ (N, NA) Symbol expires ____ (Date)

[illegible]TIFICATE OF INSPECTION

I, the undersigned holding [illegible]alid commissio[illegible]sued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of ____ and employed by ____
of ____ [illegible]ve inspected the piping described in this Data Report on ____ 19 ____
and state that to the best of my know[illegible]ge and belief, the Certificate of Authorization Holder has constructed this installation in accordance with the [illegible]E Code for Nuclear Power Plant Components.

By signing this certificate, neither the Inspector nor his employer make any warranty, express or implied, concerning the piping described in this Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.
Date ____ 19____
Signed ____ (Inspector) Commissions ____ (Nat'l Board, State, Province and No.)

Following completion of the above, the Certificate of Authorization holder accepting overall responsibility for the system shall complete the following statement.

We certify the statements made by this report are correct and that the system conforms to the rules of construction of the ASME Code Section III, Division 1.
Date ____ Signed ____ (N Certificate Holder) By ____
Certificate of Authorization Expires ____
Certificate of Authorization No. ____

SAMPLE

Figure 30-4-21B. ASME N-5 Form

Functional Inspections and Tests

Upon completion of the installation or modification and prior to the release of the system for operation, preoperational and functional testing is usually required. This testing includes, but is not necessarily limited to:

- leak tests
- flushing
- hydrostatic test
- valve tests
- pump tests
- system functional tests

The pipe per se is accepted based on the results of flushing and hydrostatic testing. The system is flushed with demineralized water to ensure it is clean and free of any undesirable chemical which could ultimately lead to corrosion. System flushing cleans inside surfaces to the specified level of cleanliness. Hydrostatic tests are typically performed at a test pressure of 125% of design and "prove" the integrity of the pressure boundaries of the system. Generally system pumps in the plant are available for this purpose. For example, the hydrostatic test for the Reactor Coolant System (RCS) for a Pressurized Water Reactor (PWR) system employs charging pumps from the Chemical and Volume Control System (CVCS), which processes the RCS water, during normal operation, but has sufficient pump head to supply the 125% of design pressure required for the hydrostatic test. During the hydrostatic test, a careful examination of the entire system is performed. Pipe-to-pipe, pipe-to-fitting, and pipe-to-component connections are most probable sources of leakage during hydrostatic testing.

In addition to flushing and hydrostatic testing, some systems are leak tested. These are systems which require very low leak rates such as refrigeration systems.

EXERCISES

The following exercises serve to reinforce the material presented in this module.

1. Following procedure #1 which is presented in the Procedures section of this module perform an inspection of piping and fitting specimen samples outlined in the procedure. Using the information presented in this module identify each specimen. Collect your data on Table 30-4-1 in the Data Table section of this module.

2. Visit a plant which contains one or more mechanical piping systems where a new system is being installed or where existing system modifications are being made. Plants of this type could include:
   - The steam heating plant at your school.
   - A manufacturing plant in your town.
   - An electrical power station in your area.
   - A water treatment plant for your town.

   a. Visit one of the above facilities during installation or system modification activities.

   b. The QA/QC technician's involvement ranges from "spot checks" to full-time verification of the installation steps. These verifications may be on a surveillance basis or specific "hold points" may be established where inspections must be performed prior to work proceeding past such hold points. The complexity of the job and the importance of the piping system to plant safety determines the extent of verifications.

   c. Using the Procedure #2 given in the Procedures section of this module along with the assistance of the QA/QC inspector at the plant site, determine if the installation processes and the installed piping system comply with the applicable specifications, drawings and procedures.

d. Use Table 30-4-2 in the Data Table section of this module to assist you during this inspection.

3. Discuss the pipe and fitting identification schemes and name the types of information identified by typical schemes.

4. Explain the difference between permanent and nonpermanent piping connections.

5. Explain the general purpose of piping preinstallation verifications and describe typical verifications.

6. Discuss why piping installation verifications are necessary and describe typical verfications.

7. Briefly describe the use of records of piping installation and verification including:
    - a. QC inspection report
    - b. Nonconformance report
    - c. Deficiency report
    - d. Code Form N-5

8. Briefly explain the purpose(s) of flushing and hydrostatic testing and describe the principle sources of leakage during hydrostatic testing.

9. Answer the following questions as either true of false:

____ a. Permanent connections are made by welding using butt or socket joints.

____ b. Nonpermanent connections are made by bolted flange, thread union, compression sleeve, flared or flareless compression fittings, soldered joints, or caulked joints.

____ c. Preinstallation verifications determine that materials, software, and site conditions are suitable for commencement of installation.

____ d. Installation verifications determine that installation processes and the completed installation comply with applicable specifications, drawings, and procedures.

____ e. Preinstallation verifications check such items as (1) materials, (2) adjacent activities, (3) protection from environment, (4) software, (5) cleanliness controls, and (6) installation and inspection check lists.

____ f. Installation verifications check such items as (1) procedural compliance, (2) component protection, (3) inspections, (4) nondestructive examinations, (5) cleanliness, (6) measuring and test equipment, (7) completed installation, and (8) records.

____ g. QA records associated with piping installations include (1) QC Inspection Report, (2) Nonconformance Report, (3) Deficiency Report, and (4) Code Form N-5.

____ h. Post installation or preoperational tests of piping include flushing, leak testing, and hydrostatic testing. Installed piping systems are accepted based primarily on the results of flushing and hydrostatic testing.

MATERIALS

The following Materials are required to support this module:

1. Pipe sample, seamless with identification ID marks.
2. Pipe sample, with seam with identification ID marks.
3. Flange Faces
4. Socket Joints
5. Flare Fittings

PROCEDURES

The following Procedures support Exercises #1 and #2 of this module.

Procedure #1: Piping and Fitting Specimen Identification
(Refer to Exercise #1)

a. Using unidentified specimens of pipe and fittings, identify both according to the following classification:

    (1) Pipe:

    - Pipe is classified as seam constructed and seamless and by method of manufacture of each class.
    - Seam constructed pipe is fabricated by one of six methods: (1) electric resistance welded pipe, (2) furnace butt welded pipe-bell method, (3) furnace butt welded pipe continuous method, (4) electric fusion welded pipe, (5) electric flash welded pipe, and (6) double submerged arc welded pipe.

- Seamless pipe is fabricated by one of five methods (1) rolled pipe, (2) forced or bored pipe, (3) extruded pipe, (4) centrifugally cast pipe, and (5) statically cast pipe.

(2) Fittings:

- Fittings are classified as welded end, bolted flanges, or compression.
- Elbows accomodate turns in piping runs.
- Tees join three piping runs at right angles
- Reducers connect two different sizes of pipe.
- Cross connections connect four piping runs at right angles.
- Laterals permit the branching of one piping run into two runs or vice versa.

(3) Piping and Fittings:

- Piping and fitting identification schemes provide for the identification of (1) name or brand of manufacturer, (2) size, (3) grade, (4) length, (5) weight per foot, (6) classification, (7) type of materials, and (8) specification for manufacturing.

(4) Identify each unknown specimen and list each in Table 30-4-1 provided in the Data Table section of this module.

Procedure #2: Installation Verification of Installation Processes and Installed Piping Systems. (Refer to Exercise #2)

a. Visit a plant in which a mechanical piping system is being installed.

b. With the assistance of the QA/QC inspector on site, determine if the installation processes and the installed piping system comply with the applicable specifications, drawings and procedures.

c. Installation verifications determine that installation processes and the installed piping system comply with applicable specifications, drawings and procedures. Items subject to installation verifications are:

   (1) Compliance with procedures such as welding, brazing, and soldering procedures.
   (2) Cleanness of components.
   (3) Protection of components from damage from handling, fixturing, and installing.
   (4) Accomplishment of inspection hold points, as applicable.
   (5) Nondestructive examinations of welds and solder joins.
   (6) Calibration of measuring and test equipment completeness of installation including gaskets, bolting, and supports and hangers.
   (7) Completion of records.

d. To assist you in the installation verification, complete Table 30-4-2 in the Data Table section of this module.

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DATA TABLE

Table 30-4-1

Piping and Fitting Identification

Specimen Number	Type of Piping or Fitting	Typical Use

Table 30-4-2

Sample Inspection Report

QUALITY CONTROL INSPECTION REPORT   1.0 QCTR. NO: ____________

2.0 SITE LOCATION: ____________   6.0 WR OR MOD NO: ____________

3.0 SYSTEM NAME/NO. ____________   7.0 CLASS I II III

3.1 COMPONENT NAME/NO. ____________   8.0 MATERIAL REPLACEMENT REQUIRED ____________

4.0 RESPONSIBLE DEPT/GROUP ________   8.1 MATERIAL CERTIFICATION REQUIRED ______

5.0 ACTIVITY LOCATION ____________   8.2 MATERIAL PURCHASE ORDER NO. ________

9.0 PROCEDURE TITLE/NO. ________________________

10.0 PREREQUISITES ACCOMPLISHED YES ____ NO____ (IF NO, EXPLAIN UNDER REMARKS)

11.0 REASONS FOR ACTIVITY:

12.0 WORK DESCRIPTION (INCLUDE MATERIAL AND COMPONENTS USED):

13.0 RETEST REQUIREMENTS:

14.0 TESTS PERFORMED:

15.0 TEST DATA:

16.0 REMARKS:

17.0 QC INSPECTOR ________________   DATE/TIME ________________

REFERENCE MATERIALS

ASME, *Boiler and Pressure Vessel Code, Section III*, The American Society of Mechanical Engineers, 1978

ASM, *Metals Handbook Vol. 6*, The American Society for Metals, 1971

LEC, *The Procedure Handbook of ARC Welding*, The Lincoln Electric Company, 1973

ASME, *Requirements for Collection, Storage and Maintenance of Quality Assurance Records for Nuclear Power Plants*, ANSI N45.2.9, The American Society of Mechanical Engineers, 1974

ASME, *Supplementary Quality Assurance Requirements for Installation, Inspection and Testing of Mechanical Equipment and Systems for the Construction Phase of Nuclear Power Plants*, ANSI N45.2.8, The American Society of Mechanical Engineers, 1975

ASME, *Power Piping*, ANSI B31.1, The American Society of Mechanical Engineers, 1973

AISI, *Carbon Steel Pipe, Structural Tubing, Line Pipe, Oil Country Tubular Goods*, American Iron and Steel Institute, 1973

AISI, *Stainless and Heat Resisting Steels*, American Iron and Steel Institute, 1974

TEST

1. Name two basic classifications of pipe.

2. Name three manufacturing methods for seam constructed pipe.
    a.
    b.
    c.
3. Name three manufacturing methods for seamless pipe.
    a.
    b.
    c.
4. Name the fitting which serves the function described:
    a. Connects three piping runs at right angles

    b. Connects larger pipe to smaller pipe on same centerline.

    c. Connects two piping runs at a right angle.

    d. Accomodates a small bend in a piping run.

    e. Accommodates a 180° turn in a piping run.

5. Name three basic classifications of fittings.
    a.
    b.
    c.
6. Name seven items of information typically included in pipe and fitting identification schemes.

7. Differentiate between permanent and nonpermanent piping connections.

8. Name two types of joints used to connect pipe and fittings by welding.
   a.
   b.

9. Name six types of nonpermanent joints used to connect pipe and fittings.

10. State the purpose of piping preinstallation verifications.

11. Name six items subject to piping preinstallation verification.

12. State the purpose of piping installation verifications.

13. Name eight items subject to piping installation verification.

14. State the purpose of each report:
    a. QC inspection report

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b. Nonconformance report

c. Deficiency report

d. Code Form N-5

15. How are inside surfaces of pipe cleaned after completion of installation?

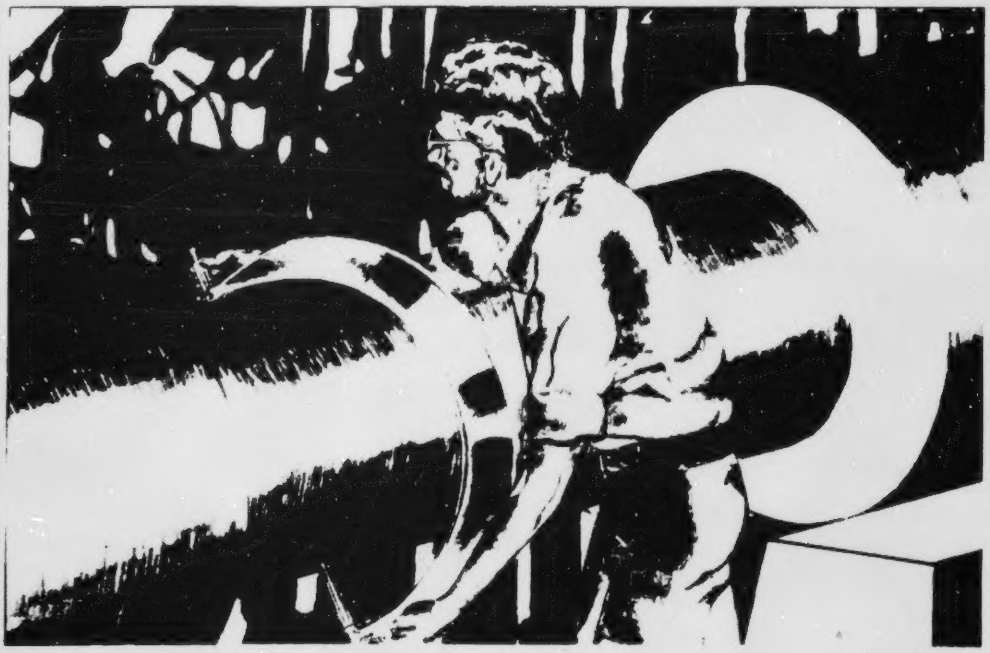
16. What test serves to "accept" the installed piping system?

17. What are the most probable sources of leakage in piping runs?

NUCLEAR TECHNOLOGY

MODULE 30-5

SURFACE CLEANING INSPECTION



COURSE 30 MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

MODULE 30-1	Pump Inspection
MODULE 30-2	Pump Functional Testing
MODULE 30-3	Valve Inspection
MODULE 30-4	Piping Inspection
⇨ MODULE 30-5	Sufrace Cleaning Inspection
MODULE 30-6	Protective Coating Inspection
MODULE 30-7	Pressure Vessel Inspection
MODULE 30-8	Rotating Equipment Inspection

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INTRODUCTION

The Nuclear QA/QC Technician normally has responsibility for inspecting product for cleanness and for monitoring plant activities for compliance with procedures pertaining to housekeeping and cleaning operations. The Technician may also audit the cleaning operations of contractors and suppliers.

Reactor systems and balance of plant systems require various levels of cleanness dependent upon the functions of the particular system. Requirements for cleanness principally stem from three concerns: (1) minimizing the introduction of soils which become radioactive during nuclear power plant operation, (2) avoiding the introduction of soils which interfere with system operation or shorten component life-time by accelerating corrosion or wear, and (3) avoiding the introduction of soils which may plug flow passages.

Cleanness requirements begin with the material suppliers and extend through component manufacture and plant construction, maintenance and modification. At each of these phases of product life, the soils introduced by the work activities may vary considerably. For example, steel mills may be mostly concerned with removing heavy oxide scales or sand (silica) inclusion on surfaces. Manufacturers may be mostly concerned with removing machining and cutting oils. Constructors may be mostly concerned with removing welding fluxes and light oxide films. While there are a number of cleaning methods available, the cleaning method selected for use must be capable of cleaning the types of soils encountered.

This module initially describes cleaning methods and their capabilities. Regardless of where these cleaning methods may be used, the student/trainee will recognize the principle elements of each cleaning process and its general use. The module then describes cleaning activities which typically apply to construction, maintenance, and modification activities at the nuclear power plant site. It is at the power plant site that the majority of duties of the Nuclear QA/QC Technician are performed.

A glossary of terms is given at the end of the module. The student/trainee should refer to the glossary as new terms are encountered.

MODULE PREREQUISITES

There are no prerequisites for this module.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Define the terms: cleaning, contamination, crevice, dead leg, flushing, inaccessible area, and layup.
2. Briefly describe the cleaning process and types of soils removed for any of the cleaning methods of solvent, emulsion, acid, chelating, vapor degreasing, abrasive blasting, salt bath descaling, and alkaline.
3. Name four cleanness classification levels, briefly describe the degree of cleanness associated with each level, and associate types of components or systems with their normal cleanness classification.
4. Given any of the following cleanness control activities: cleanness classification, preinstallation cleanness,

installation cleaning, maintenance of installation cleanness, preoperational cleaning, layup, and housekeeping. State the purpose of the activity and briefly describe how it is accomplished.

5. Describe typical preparations for flushing which are associated with any of the following topics: other plant activities, personnel readiness, circulating flow paths, component protection, and water quality.
6. Describe typical water treatment for wet layup.
7. Demonstrate ability to visually inspect components for compliance with specified cleanness requirements.

NOTES TO INSTRUCTOR / STUDENT

Three activities are included in this module. The first consists of word descriptions of product from which the student/trainee must determine acceptability of cleanness and, if unacceptable, specify an adequate cleaning method. Actual product, if available, should be substituted for the word descriptions. The other two activities are considered optional. These would require the student/trainee to perform a Jackson Turbidity and a Titration.

SPECIFIC CLEANING METHODS

Eight Methods

Two primary factors govern the selection of the specific cleaning method. These factors are the type of soil encountered and the effect of the cleaning operation on the product. Sometimes, more than one method is necessary to remove all soils encountered for given product. Eight cleaning methods are common: solvent cleaning, emulsion cleaning, acid cleaning, acid pickling, chelating, vapor degreasing, abrasive blasting, salt bath descaling, and alkaline cleaning.

The eight cleaning methods are used primarily by component and materials suppliers to clean items prior to delivery to the nuclear power plant construction site. Construction activities attempt to maintain cleanness of the items from receipt through installation. But when construction activities introduce soils, an appropriate cleaning method is selected to reclean the item.

Solvent Cleaning

Solvent cleaning is a process for removing organic soils from the surfaces of components by the use of organic solvents. The most common organic solvents in use are aliphatic petroleums, chlorinated hydrocarbons, or blends of these two classes of solvents. Table 30-5-1 lists the commonly used solvents.

Of the solvents listed in Table 30-5-1, Stoddard solvent and mineral spirits are the most widely used due to their low cost and comparatively high flash points. The chlorinated hydrocarbons are excellent solvents and are nonflammable but are more toxic than the aliphatic petroleums. In many cases, mineral spirits is mixed with 25 to 50% of a

Table 30-5-1. Cleaning Solvents

Solvent	Flash Point, F(a)	Toxicity, ppm(b)
Aliphatic Petroleums		
Kerosene	145	....
Naphtha, hi-flash	110	....
Mineral spirits	57	500
Naphtha, VM&P	48	500
Stoddard solvent	105	500
Chlorinated Hydrocarbons		
Chloroform	None	50
Methylene chloride	None	500
Perchlorethylene	None	100
Trichloroethane (1,1,1)	None	500
Trichlorethylene	None	100
Trichlorotrifluoroethane	None	1000
Alcohols		
Ethanol, SD	57	1000
Isopropanol	50	400
Methanol	54	200
Other Solvents		
Acetone	0	1000
Benzol	12	25
Cellosolve (c)	104	200
Toluol	40	200

(a) Tag closed cup. (b) Threshold limit values, adopted at 1962 meeting of American Conference of Governmental Industrial Hygienists, expressed as parts of vapor or gas per million parts of air by volume at 25 C and 760 mm Hg pressure. These values should not be regarded as precise boundaries between safe and dangerous concentrations. They represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day, without adverse effect. The values refer to time-weighted average concentrations for a normal workday. (c) 2-ethoxyethanol.

chlorinated hydrocarbon to reduce fire hazard. The alcohols are used for special solvent cleaning operations such as the removal of activited soldering fluxes. Acetone and other solvents which have low flash points are used for special purposes only, such as cleaning the components of precision instruments. Acetone and Benzol constitute a serious fire hazard. Their use and storage require strict observance of safety precautions. Solvents such as methylene chloride and chloroform are frequently used in the spray cleaning of relay contactors before they are sealed by covers. Fumes from these sprays must be thoroughly vented.

Solvent cleaning is usually performed at, or slightly above, room temperature. The components are cleaned by either immersion, spraying, or wiping. Agitation of the component assists in the cleaning process. Ultrasonic cleaners use a solvent and ultrasonic sound to vibrate the part. In this manner, removal of soils from deep recesses or other difficult to reach areas is facilitated by ultrasonic vibration.

Traditionally, solvent cleaning is regarded as a method of pre-cleaning or as one reserved for special applications. However, in the manufacture of electronic components and other assemblies that are comprised of many small parts, the use of solvents as a final cleaner has increased. Most solvent cleaning operations fall within one of the following categories:

- Inexpensive pre-cleaning of components that later will be further cleaned by another method.
- Hand cleaning of components too large for immersion or spray machine cleaning.
- Cleaning of heat sensitive or chemical sensitive components.
- Removal of organic materials such as plating stop-offs, marking crayons or soldering fluxes.

- Cleaning of precision items in a succession of steps in which the component is first cleaned in nonpolar solvent to remove oil and then in water (polar solvent) to remove inorganic solvents.
- Temporary general cleaning where the cost of vapor degreasing equipment is not justified.
- Cleaning of electrical or electronic components in which the presence of inorganic salt deposits may cause current leakage.

Safety precautions for fire and toxicity are necessary when solvents are used. (See Table 30-5-1) Typical precautions are:

- Storage and use of flammable solvents in metal containers, such as safety cans.
- Adequate ventilation to prevent the accumulation of vapors and fumes.
- Prohibited use of solvents close to an open flame or heaters with open coils.
- Protection against exposing the skin to solvents. (Protective gloves and/or ointments should be used to prevent extraction of natural oils from the skin which would cause cracking of the skin)
- Protection from inhalation when toxic solvents are used (The vapors of chlorinated hydrocarbons and alcohols are capable of exerting a potentially anesthetic action when inhaled. As an example, trichloroethylene has relatively slight toxic effect, but maintenance personnel have lost their lives after working for prolonged periods inside tanks containing high concentrations of trichloroethylene vapor, as a result of its strong narcotic effect. Perchlorethylene is comparable in toxicity and also is strongly narcotic.)

Emulsion Cleaning

Emulsion cleaning is a process for removing organic soils from the surface of a metal by the use of common organic solvents dispersed in an aqueous medium with the aid of an emulsifying agent. Dependant upon the solvent used, cleaning is performed at temperatures ranging from room temperature to 180°F,

An emulsion system contains two liquids, mutually insoluble, one of which is "dispersed" and the other is "continuous". The "dispersed phase" (also discontinuous phase) is that liquid which is distributed as globules in the other liquid, known as the "continuous phase" liquid. Emulsifying agents are used to permit use of solvent-water emulsions. There are two general types of emulsifying agents: Those that promote the formation of oil-in-water emulsions (water constitutes the continuous phase), and those which form water-in-oil emulsions (water is the dispersed phase).

Emulsion cleaners are classified into four groups on the basis of stability given by the emulsifying agent. There is some overlapping of definitions.

- Stable, Stable Single Phase, or Permanent Emulsions Cleaners - The emulsion is dispersed throughout the continuous phase. The agitation provided by thermal gradients and the motion of the work being cleaned is sufficient to maintain a uniform dispersion.
- Unstable or Unstable Single Phase Emulsion Cleaners - These have a uniformly dispersed discontinuous phase, but require moderate to considerable agitation to maintain dispersion.
- Diphase, Multiphase, or Floating Layer Emulsion Cleaner - These are highly unstable, and form two layers in the cleaning tank. (Work is immersed through the oil-rich surface layer into the water-

rich lower layer. This permits both phases to come in contact with the surface to be cleaned. When used in a spray system, this type of emulsion cleaner resembles an unstable emulsion as the oil and water phases are mixed in the pumping action.)

- Emulsifiable-Solvent System - This process applies a concentrated solvent to the surface to be cleaned followed by a water spray rinse which emulsifies and removes the solvent and soil.

Emulsion cleaners cover a wide range of solvent and emulsifier compositions. The solvent is generally of petroleum origin and typically is paraffinic*, napthenic, or aromatic.** Solvents have boiling points ranging from 140 to 500°F and flash points ranging from room temperature to above 200°F. The lower-boiling solvents are usually more effective in removing soils. However, fire hazards and evaporation losses increase as boiling and flash points decrease.

Emulsifiers include polyethers and high-molecular-weight sodium or amine soaps of hydrocarbon sulfonates, amine salts of alkyl aryl sulfonates, fatty-acid esters of polyglycerides, glycerols, of polyalcohols. Emulsifiers must have some solubility in the oil phase. When solubility is low, a blending agent such as ester or ether, is added to increase solubility. The blending agent must be soluble in oil and water.

Typical compositions and operating temperatures ranges for emulsion concentrates are illustrated in Table 30-5-2.

---

* a hydrocarbon of the methane series

** characterized by the presence of at least one benzene ring - used of hydrocarbons and their derivatives.

Table 30-5-2. Typical Emulsion Concentrations

	Composition, parts by volume		
Component	**Stable**	**Unstable**	**Diphase**
Petroleum solvent (a)	250 to 300	350 to 400	250 to 300
Soaps (b)	10 to 15	15 to 25	None
Petroleum (or mahogany) sulfonates (c)	10 to 15	None	1 to 5
Nonionic surface-active agents (d)	5 to 10	None	1 to 5
Glycols, glycol ethers (e)	1 to 5	1 to 5	1 to 5
Aromatics (f)	5 to 10	25 to 50	5 to 10
Water (g)	5 to 10	None	None
Typical Operating Temperature Range (h)	80 to 150 F	80 to 150 F	80 to 140

(a) Two commonly used hydrocarbon solvents are deodorized kerosene and mineral seal off. (b) Most commonly used soaps are based on rosin or other short-chain fatty acids, saponified with organic amines or potassium hydroxide. (c) Low-molecular-weight petroleum sulfonates ("mahogany sulfonates") are used for good emulsification plus some rust protection. High-molecular-weight sulfonates offer good rust inhibition and fair emulsification. (d) Increased content generally improves stability in hard water, but increases cost. (e) Glycols and glycol ethers are generally used in amounts necessary to act as "couplers" in the stable and unstable types of emulsions. These agents are frequently used with diphase and detergent cleaners to provide special consolvency of unique or unusual types of soils. (f) Aromatic solvents are frequently used to provide consolvency for special or unique soils; sometimes they serve also to inhibit odor-causing or rancidifying bacteria. (g) Water or fatty acids, or both are used to adjust the clarity and stability of the emulsion concentrate, particularly those of the stable and unstable types. (h) Maximum safe temperature depends on the flash point of the hydrocarbon (petroleum) solvent used as the major component.

Emulsion cleaning is an effective means of removing pigmented drawing lubricants, unpigmented oils, and greases, cutting fluids, polishing and buffing residues, and residues resulting from magnetic particle inspection. Emulsion cleaning is used when rapid superficial cleaning is required and when protection by a light residual film of oil is desirable, or is not objectionable. Emulsion cleaners can be used on virtually any metal as long as the pH of the cleaner is maintained below 10.0. If the cleaner initially has a pH > 10.o or if alkali contamination has brought it above 10.0, the cleaner is not recommended for the cleaning of aluminum or zinc. Emulsion cleaners leave a thin film of oil which provides some protection against rusting.

Emulsion cleaning is not recommended for components that are difficult to thoroughly rinse. Such components are exemplified by sintered powder metallurgy components and components which have blind holes or deep recesses.

Emulsion cleaners have negligible toxicity and irritation to the skin. The fire hazard associated with emulsion cleaners is slight if the temperature of the cleaner is maintained 15 to 20°F below the flash point and adequate ventilation is maintained. Emulsion cleaners containing Stoddard solvent, kerosene, or similar petroleum derivatives, have relatively low flash points and present a potential fire hazard. These cleaners should be kept away from welding, heat treating and similar heat generating operations. Open fire burners of all types must be kept away from emulsion cleaning operations. If it is required to heat the emulsion cleaner, steam is used as the heating medium.

The rate of ventilation required for health and safety reasons is dependent upon the cleaner characteristics, operating temperature, and the efficiency of the baffles on cleaning machines. The removal rate of volatiles varies from as little as 1 to 250 cfm for each square foot of cleaner surface area. Spray operations require more ventilation than immersion operations because the area of air/liquid interface and the velocity are greater.

Acid Cleaning

Acid cleaning is a process in which a solution of a mineral acid, organic acid or acid salt, in combination with a wetting agent and detergent, is employed to remove oxide, shop soil, oil, grease, and other contaminants from metal surfaces, with or without the application of heat. The distinction between acid cleaning and acid pickling is a matter of degree. Generally, acid pickling refers to a more severe treatment for the removal of scale from semi-finished mill products, forgings or castings. The term acid cleaning is used when the acid solution is employed for final or near final preparation of metal surfaces prior to plating, painting or storage.

Acid cleaners consist of many combinations of mineral and organic acids and solutions of acid salts. These acids may employ the use of surfactants (wetting agents), inhibitors, and solvents. With respect to composition, the many formulations of which acid cleaners are comprised can be classified as (1) Inorganic (mineral) acid solutions, (2) Organic acid solutions, (3) Mixtures of (1) and (2), (4) Acid-solvent mixtures, and (5) Solutions of acid salts.

Compositions and operating conditions of several typical formulations used for cleaning ferrous metals are listed in table 30-5-3.

The phosphoric acid-ethylene glycol monobutyl ether mixtures are widely used for removing grease, oil, drawing compounds, and light rust from iron and steel. These mixtures are adaptable to immersion, spray or wiping methods and leave a phosphate coating which provides a paint base and temporary resistance to rusting. Mixtures containing chromic acid are often used as final rinses in acid cleaning-phosphating systems. The chromic acid enhances the corrosion resistance of the surface and enables the rinse to clean excess and unattached phosphate from the surface of the metal without leaving hard water salts deposited on the surface.

Table 30-5-3. Acid Cleaner Formulations and Conditions for Cleaning of Ferrous Metals.

	Immersion		Spray		Barrel	Wipe	Electrolytic
			Composition, % by Weight				
Phosphoric acid..........	70	....	70	....	....	15 to 25	....
Sodium acid pyrophosphate	....	16.5	....	16.5	16.5	....	....
Sodium bisulfate.........	....	80	....	80	80	....	....
Sulfuric acid............	....	....	....	....	....	....	55 to 70
Nonionic wetting agent(A)	5	....	5	....	....	7 to 20	....
Anionic wetting agent....	(B)	(B)	(B)(C)	(B)(C)	(B)(C)	(B)(D)	(B)
Other Additives..........	25(B)	....	25(E)	....	....	Rem	Rem
			Operating Conditions				
Concentration, oz per gal	16	8 to 16	8	2 to 4	2 to 8	....	....
Current density, amp/sq ft	....	....	....	....	....	....	100
Temperature, F...........	160	140	140	140	Room	Room	70

(a) Ethylene glycol monobutyl ether is commonly used. (B) Inhibitors up to 1% concentration may be used to minimize attack on metal. (C) An antifoaming agent is usually required when the cleaner is used in a spray or barrel system. (D) Small additions of sodium nitrate are often used as an accelerator in cleaning rolled steel; nickel nitrate is used in cleaning galvanized steel. (E) Before dilution.

To reduce the amount of acid attack on the metal, inhibitors are included in cleaners used on ferrous metals. Both naturally occurring and synthetic inhibitors are used in acid cleaning although naturally occuring inhibitors vary widely in uniformity and effectiveness. For this reason, the use of synthetic inhibitors is increasing. Examples of naturally occuring inhibitors are waste animal materials, off-grade wheat flour, and sulfonation products of such materials as tar, coal tar, and asphaltum. Synthetic inhibitors are exemplified by complex structures of amines, aldehydes, thioaldehydes, mercaptans and other organic compounds. The amount of inhibitor required is dependent upon the workpiece composition, acid cleaner formulation, temperature of operation and the nature of the soil to be removed. Increasing the solution operating temperature increases the rate of attack in both inhibited and uninhibited acid cleaning solutions.

Antifoaming agents may be required to prevent excessive foaming in acid spray systems. In many cases, foaming can be reduced by the use of hard water and by the addition of small amounts of calcium chloride. Addition of one of the high molecular weight polyols or a plasticizer such as triethylhexylphosphate will reduce foaming. Silicones are usually effective as antifoaming agents although they are not recommended if the components are to be plated or painted. Such an application produces contamination that causes "fisheyes" on the finished component. From plant to plant, it may be necessary to try several different antifoaming agents before foaming is brought under control due to the variations in water and other conditions.

The selection of a method of acid cleaning is dependent upon the nature of the soil to be removed, the size and configuration of the workpiece, the quantity of similar pieces to be cleaned, and the type of acid cleaner used. Methods include wipe on-wipe off, spraying, immersion, rotating barrel, and electrolytic.

- Wipe on-wipe off method - This is the most simple method. A suitably protected operator wipes the soiled workpiece with an acid-impregnated cloth or sponge. After the cleaner is allowed to react, the work is rinsed with water. Reaction times of 2 to 3 minutes is usually sufficient. The wiping method is practical for cleaning a few components at a time or for large, bulky components that can not be immersed conveniently in a cleaning bath.

- Spray cleaning method - This method is more practical for large quantities of bulky components. The types of acid cleaners that are practical for spray cleaning is somewhat limited. Table 30-5-3 illustrates the typical formulations used in spray acid cleaning systems. Strong acids such as sulfuric and hydrochloric are infrequently used for this method. Multistage spray washers have been designed to accomodate a large variety of work that can be racked or suspended from hooks.
- Immersion method - The most versatile of acid cleaning methods is the immersion system. Any type of acid cleaner may be employed. Immersion system operation varies from dipping a single part or agitating a basket containing several parts in an earthenware crock at room temperature, to a sophisticated, automatic agitation system operating at elevated temperatures.
- Barrel (tumbling) method - In this method, perforated barrels containing 500 to 1000 pounds of work is immersed and rotated in tanks containing the acid salts. Barrel acid cleaning is used for large quantities of small parts. A medium such as stone is included in the barrel to improve cleaning by providing an abrading action and to prevent the workpieces from damaging each other.
- Electrolytic method - In electrolytic cleaning, an electric current is passed through the acid bath. Sulfuric acid baths are mostly used. The mechanical scrubbing resulting from the evolution of gas and the chemical reduction of surface oxide films make electrolytic cleaning effective. Phosphoric acid is unsuitable for electrolytic cleaning due to the excessive evolution of gas. To prevent the excessive

contamination of the electrolytic bath, major amounts of grease and oil are removed prior to electrolytic cleaning. When alkaline cleaners are used as pre-cleansers, a thorough rinse is accomplished prior to the electrolytic bath to prevent alkali contamination of the bath. Electrolyzed acid solution time cycles must be short, usually less than two minutes, or excessive etching will occur. Current distribution must also be uniform or localized etching may damage the component.

Any acid cleaning normally etches the item. Although advantageous for many final finishing operations, when etching is not permissible, some other cleaning method must be employed. Limitations of acid cleaning include (1) Inability to remove heavy deposits of oil or grease without the addition of expensive material such as ethylene glycol monobutyl ether, (2) metal attack to some degree even when inhibitors are used, and (3) requirement for acid-resistant equipment.

Acid Pickling

Pickling is the chemical removal of surface oxides from metal by immersion in an acid solution. Pickling is the most efficient method of scale removal for large tonnage products such as merchant bars, blooms, billets, sheet, strip, wire and tubing.

The most commonly employed pickling acid is sulfuric acid. Table 30-5-4 illustrates some typical solution concentrations and operating temperatures employed for pickling carbon and alloy steel products.

For batch pickling of hot rolled or heat treated high-carbon steel rod and wire, hydrochloric acid is preferred. Hydrochloric acid produces a uniform light-gray surface and decreases the possibility of overpickling, which produces a black smut on the surface. Operating conditions for batch and continuous pickling in hydrochloric acid solutions are illustrated in Table 30-5-5.

Table 30-5-4

Typical Solution Concentration and Operating Temperatures Employed for Pickling Carbon and Alloy Steel Products

Product	Sulfuric acid concentration, % by weight		Bath temperature, F	
	Min	Max	Min	Max
Bars, low-carbon	7	15	155	185
Bars, alloy	9	12	150	170
Billets, low-carbon	7	12	165	180
Billets, alloy	9	12	180	200
Pipe for galvanizing	7	15	160	190
Sheet for galvanizing	4	12	150	170
Sheet, tin plant (white pickle)	9	12	150	185
Strip, soft	6	12	170	190
Strip, alloy and high-carbon	7	12	150	170
Strip, continuous pickling	23	38	170	212
Tubing, low-carbon seamless	7	12	170	190
Tubing, high-carbon and alloy structural	9	12	160	200
Tubing (over 0.40% C)	9	12	140	160
Wire, soft	4	11	170	190
Wire, alloy and high-carbon	3	7	145	165
Fabricated parts (for tinning):				
Initial pickle	5	10	150	190
Final dip	Conc HCl, 18-20° Be'		...	100

Table 30-5-5. Hydrochloric Acid Solution

	Batch	Continuous
HCL, & by Weight	8 to 12	15 to 20
Temperature, F	100 to 105	120 to 140
Immersion Time	5 to 15 minutes	1 to 20 seconds
Maximum Allowable Iron Concentration in Bath, % by Weight	13	5 to 8

As in acid cleaning, natural or synthetic inhibitors are added to the acid pickling solutions. Inhibitors are added primarily to protect the steel being cleaned by retarding or stopping the chemical action of the acid on the base metal. Inhibitors perform five functions in the pickling process: (1) Minimize the loss of iron, (2) Reduce the extent of hydrogen embrittlement*, (3) Protect the metal against pitting, caused by over-pickling and poor surface quality, (4) Reduce acid fumes resulting from excessive reaction between the acid and the base metal, and (5) Reduce acid consumption.

Chelating

Chelating is a process for removing organic and inorganic soils by the use of chelating agents. Cold working operations require the use of drawing lubricants which contain compounds of zinc, magnesium, calcium, or iron. Such lubricants are difficult to remove but can be cleaned with alkaline cleaners containing the proper chelating agents. A chelate is a ring structure that usually contains a metal ion held by coordination bonds. Chelates accelerate cleaning by reacting with the metal ion in the lubricant to form a metal chelate and an acid. As an example, a calcium stearate type of lubricant is only slightly soluble in an alkaline solution. However, when the proper chelating agent is present in the solution, the calcium ions which go into solution combine with the chelate to form metal chelate molecules. As the calcium ions combine with the chelate, more calcium stearate dissolves and the cleaning process rapidly progresses to completion.

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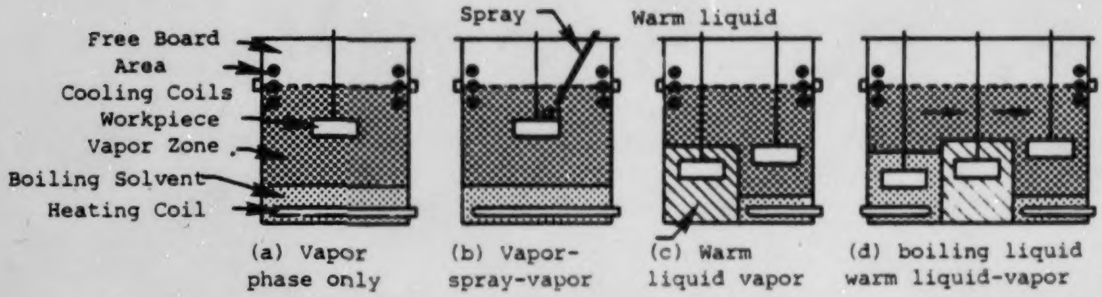
* Hydrogen embrittlement is a mechanical-environmental failure process that results from the initial presence or absorption of excessive amounts of hydrogen in metals, usually in combination with residual or applied tensile stresses. In some types of hydrogen embrittlement, cracking is promoted by high internal pressure caused by the combination of atomic hydrogen into molecular hydrogen gas at internal discontinuities or inclusions of the metal. It has been suggested that hydrogen enhances cracking because hydrogen absorption at these sites lowers the surface energy required for cracks to grow. Another suggestion is that hydrogen reduces the bonding energy of the metal lattice sufficiently to allow cracking.

Sodium salts are combined with the chelating agents to form a dry, concentrated powder. The cleaning solution is produced by dissolving the powder in water. The chelates commonly used in alkaline cleaning solutions are citric acid, ethylenediamine tetraacetic acid (EDTA), gluconic acid, and nitrilatriacetic acid.

Vapor Degreasing

Vapor degreasing is a term applied to the cleaning process which employs the hot vapors of a chlorinated solvent to remove soils. Vapor degreasing is effective in the removal of oils, greases, and waxes.

Vapor degreasing is accomplished by the use of a vapor degreasing unit. The unit consists of an open steel tank with a heated solvent reservoir (sump) at the bottom. A cooling zone is located near the top of the tank. Heat is introduced into the sump to boil the solvent and generate hot solvent vapor. As the hot vapor is heavier than air, it displaces the air and fills the tank up to the cooling zone. As it reaches the cooling zone, the hot vapor is condensed thereby maintaining vapor level and creating a thermal balance. The temperature differential between the hot vapor and the cool workpiece causes the vapor to condense on the workpiece and dissolve the soil. As a supplement to vapor cleaning, some degreasing units are equipped with facilities for immersing the work in warm or boiling solvent and for spraying the workpiece surfaces with clean solvent. The efficiency of the liquid phase of the cleaning cycle can be increased with the use of ultrasonic vibration. Figure 30-5-1 illustrates the principle systems of vapor degreasing.



(a) Vapor phase only (b) Vapor-spray-vapor (c) Warm liquid vapor (d) boiling liquid warm liquid-vapor

Figure 30-5-1. Principal Systems of Vapor Degreasing

The degreasing system of simplest form is the Vapor Phase Only system. The workpiece is lowered into the vapor zone. The relative coolness of the workpiece causes the vapor to condense on the workpiece. The soil is dissolved and removed from the workpiece by the condensate dripping back into the boiling solvent. As the workpiece approaches the temperature of the hot vapor, condensation and cleaning action cease.

When a workpiece contains blind holes or recesses which are not accessible to the vapor, the Vapor-Spray-Vapor method of vapor degreasing is employed. Preliminary cleaning is accomplished by the vapor phase. When condensation ceases, the workpiece remains in the vapor zone and is sprayed with warm solvent. The pressured spray forces liquid solvent into the blind holes and removes stubborn soils that can not be removed by vapor alone. The temperature of the workpiece is also lowered by the liquid spray, allowing further condensation of vapor for a final rinse.

Temperature equalization may occur prior to completion of workpiece cleaning on workpieces which are comprised of small parts with thin sections. The Warm Liquid-Vapor System of vapor degreasing is recommended in this case. The workpiece is held in the vapor zone until condensation ceases. The workpiece is then lowered into warm liquid solvent where agitation mechanically removes some of the soil and the temperature of the workpiece is lowered. From the warm liquid, the workpiece is transferred to the vapor zone for a final rinse.

The fourth method of vapor degreasing is the Boiling Liquid-Warm Liquid-Vapor System. This method provides satisfactory cleaning of small workpieces which are nested or packed closely together in baskets and for workpieces which have particularly heavy or adherent soil. In this system, the workpiece may be held in the vapor zone until condensation ceases and lowered into the boiling liquid, or the workpiece may be lowered directly into the boiling liquid. The boiling liquid scrubs off most of the heavy deposit as well as metal chips and insolubles. The work is transferred to the warm liquid which removes dirty solvent and lowers the workpiece temperature. The workpiece is finally transferred to the vapor zone where condensation provides a final rinse.

Ultrasonic degreasing can be used in conjunction with vapor degreasing. Cleaning efficiency of the liquid phase of vapor degreasing is significantly increased by the application of ultrasonic energy. Ultrasonic degreasing is often applied to components that are too small or intricate to receive maximum benefit from conventional degreasing cycles. Examples of components cleaned by ultrasonics because they failed to respond to conventional degreasing methods are: small ball bearing and shaft assemblies, printed circuit boards (removal of soldering flux), intricate relays, plug-type valve inserts (contaminated with lapping compounds), and strands of cable (removal of soil and other manufacturing contaminants trapped between the strands).

Vapor degreasing system use chlorinated hydrocarbons which are toxic when inhaled. Chlorinated hydrocarbons affect the mucous membranes and the linings because they extract oil from the skin which may cause cracking and dermatitis. Prolonged or repeated exposure of the skin to these solvents should be avoided. Properties of vapor degreasing solvents are listed in Table 30-5-6.

Table 30-5-6. Properties of Vapor Degreasing Solvents

Property	Trichlor-ethylene	Perchlor-ethylene	Methylene chloride	Trichloro-trifluoro-ethane	Methyl chloroform (1.1.1-tri-chloroethane)
Boiling point, F	188	250	104	118	165
Flammability	Nonflammable under vapor degreasing conditions				
Kauri-butanol value	130	90	135	30	130
Latent heat of vaporization (a)	103	90	142	63	95
Saturation in air (b)	0.033	0.008	0.19	0.27	0.06
Specific heat (c)	0.23	0.21	0.28	0.21	0.26
Specific gravity:					
Vapor (air = 1.00)	4.54	5.73	2.93	6.75	4.50
Liquid (water = 1.00)	1.464	1.623	1.326	1.514	1.327
Threshold limit, ppm (d)	100	100	500	1000	500

(a) At boiling point, in Btu per pound. (b) 100% relative humidity at 68°F, in pounds of solvent per cubic foot of air. (c) Of liquid, in Btu per pound per °F. (d) Parts of vapor or gas per million parts of air by volume at 25 C and 760 mm Hg pressure; values adopted at 1962 meeting of American Conference of Governmental Industrial Hygienists. These values should not be regarded as precise boundaries between safe and dangerous concentrations. They represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect. The values refer to time-weighted average concentrations for a normal workday.

Abrasive Blast Cleaning

Abrasive blast cleaning is the forceful direction of abrasive particles (either dry or suspended in a liquid) against the surfaces of metal components to remove contaminants or to condition the surfaces for subsequent finishing. Abrasive blast cleaning is used to (1) remove rust, scale, dry soils, weld sand or paint, (2) roughen the surfaces in preparation for bonding, painting, or other coating, (3) remove burrs, and (4) develop a matte surface finish.

The materials used in dry abrasive blast cleaning may be categorized as grit, shot, "sand", and miscellaneous. Grit consists of angular metallic particles (usually, crushed hardened cast steel, which may be tempered, or chilled white cast iron, with high cutting power. Shot is normally made of the same materials as grit and is usually in the form of spherical particles; it removes scale, sand and other surface contaminants by impact. Shot also may be made of aluminum or cut steel wire. Cut steel wire deforms into rounded particles during usage. "Sand" is a term applied to a wide diversity of nonmetallic abrasives in addition to ordinary silica sand. These materials are used when it is necessary to protect the surface of the workpiece from metallic contamination. they may be either natural materials (such as garnet, novaculite, dolomite, pumice and flint quartz) or manufactured materials (such as aluminum oxide, silicon carbide and slag). Miscellaneous Materials give a mild abrasive action and include such agricultural products as crushed walnut or pecan shells, rice hulls, rye husks, corncobs and sawdust. Smooth glass or plastic beads service a similar purpose. Table 30-4-7 lists typical abrasives for various applications. Regardless of the materials used for dry blasting, the following generalizations apply.

- As abrasive particle size decreases, the surface finish is finer and surface coverage is greater.
- As abrasive particle increases in size, the impact is greater resulting in more upsetting of metal (pruning or cutting).
- As abrasive particle hardness increases, cleaning action is faster.

Table 30-5-7

Typical Abrasives, Equipment and Cycles Employed for Dry Blasting

		Abrasive		Equipment		
Material or product	Reason for blasting	Type	Size No.	Type	Horsepower or nozzle diameter	Blasting cycle
		Ferrous Metals				
Cast iron	Prepare for zinc impregnation	Iron grit	G80	Air, table(a)	¼ in.	1 hr
	Remove molding sand	Steel shot	S230	Wheel, barrel	15 hp	10 min
Cold rolled steel	Remove graphite for painting	Iron grit	G80	Wheel, barrel	15 hp	10 min
				Air, table(a)	¼ in.	40 min
Gray iron exhaust manifolds, bearing caps	Clean for machining	Malleable iron shot	S460	Wheel, tumble(b)	80 hp	1500 pieces per hr
Gray iron motor blocks and heads	Remove sand and scale after heat treatment	Malleable iron shot	S550	Wheel, blast cabinet(c)	150 hp	0.19 to 0.27 min per piece
Hardened steel screws	Remove heat treat scale	Iron grit	G80	Wheel, barrel	10 hp	5 min
Hot rolled steel	Prepare for painting	Iron grit	G80	Air, table(a)	¼ in.	1 hr
Malleable iron castings	Prepare for galvanizing	Steel grit	G50	Wheel, barrel	40 hp	15 min
Pole-line hardware	Prepare for galvanizing	Steel grit	G50	Wheel, barrel	40 hp	15 to 20 min
Round steel bar	Etch for adhesive coating	Iron grit	G80	Air, blast room	¼ in.	2 min
Soil-pipe fittings	Remove molding sand	Steel shot	S330	Wheel, barrel	30 hp	400 lb in 5 min
Steel drums	Prepare for painting	Iron grit	G80	Air, blast room	¼ in.	4 min
Steel rod	Clean for wiredrawing	Steel grit	G40	Wheel, continuous(d)	80 hp	40 to 300 fpm
Steel screws	Prepare for plating	Iron grit	G80	Air, barrel(a)	5/16 in.	20 min
Structural steel	Prepare for painting	Steel grit	G40	Wheel, continuous(d)	80 hp	30 fpm
Weldments (steel)	Remove scale, welding flux and spatter, for painting	Steel grit	G25	Wheel, barrel	30 hp	300 to 600 lb in 7 min
		Nonferrous Metals				
Aluminum	Produce frosted surface	Sand	50	Air, barrel	¼ in.	20 min
	Prepare for painting	Iron grit	G80	Wheel, barrel	15 hp	5 min
Bronze	Produce frosted surface	Sand	50	Air, barrel	¼ in.	20 min
		Nonmetallic Materials				
Clear plastic parts	Produce frosted surface	Sand	50	Air, barrel	¼ in.	15 min
Hard rubber	Improve appearance	Sand	50	Air, barrel	¼ in.	20 min
Molded plastic parts	Remove flash	Walnut shells	...	Wheel, barrel	10 hp	8 min
Phenolic fiber	Produce frosted surface	Sand	50	Air, barrel	¼ in.	30 min
	Prepare for painting	Sand	50	Air, barrel	¼ in.	20 min

(a) Four air nozzles. (b) Two wheels, 40 hp each. (c) Six wheels, 25 hp each. (d) Four wheels, 20 hp each.

The two basic methods of dry blast cleaning are mechanical and air blasting. Mechanical blasting consists of the abrasive being propelled by means of a power-driven, rapidly rotating, bladed wheel. Air blasting consists of the abrasive being propelled through a nozzle by compressed air.

The abrasive particles employed in wet blast cleaning are usually finer than those in dry blast cleaning. The abrasive particles are suspended in chemically treated water to form a slurry. The slurry is continuously agitated to prevent settling and is forced by compressed air through nozzles which are directed at the workpiece.

Wet blasting is not intended for the removal of heavy scale, coarse burrs or heavy soil. The wet blasting method of abrasive cleaning is intended to produce only relatively slight effects on the workpiece surface. Wet blasting is commonly used for:

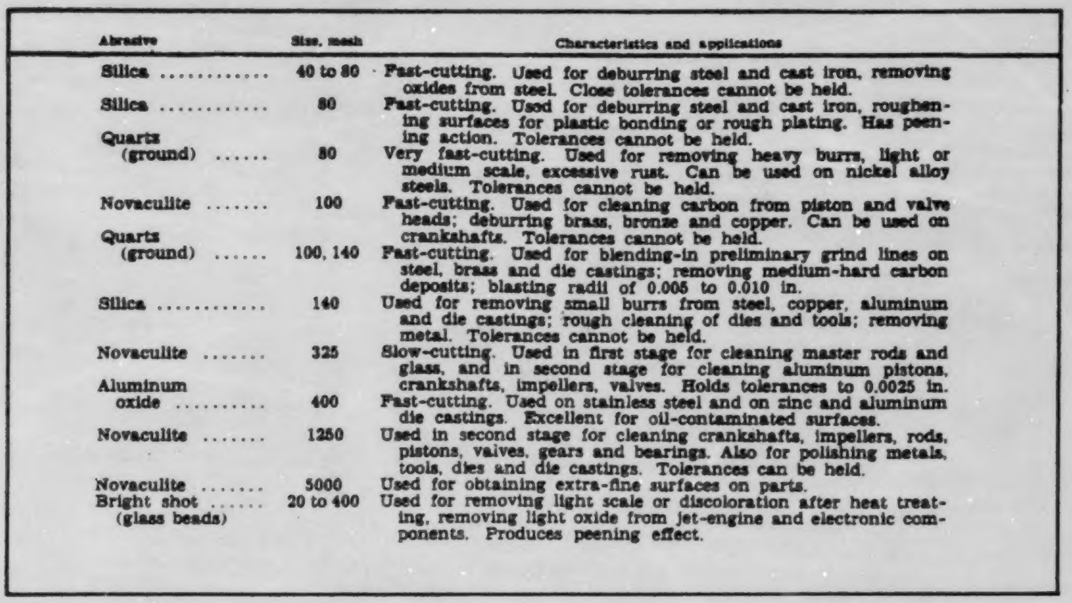
- removing small burrs on precision parts
- production of satin or matte finishes
- inspecting finish ground hardened parts
- removing fine tool marks from hard parts
- removal of light mill scale or machining marks preparatory to plating
- removal of surface oxide preparatory to soldering of electronic components and painted circuits
- removal of welding scale

In the majority of instances, precleaning is accomplished prior to wet blasting to prevent contamination of the slurry. Protective coatings, grease and heavy oil are removed by conventional degreasing methods prior to wet blasting. A light layer of rust may be removed by wet blasting without precleaning. Generally, however, the finer the abrasive used in the wet blast slurry, the greater is the need for precleaning to preclude slurry contamination.

Numerous kinds and sizes of abrasives are used in wet blasting. Table 30-5-8 lists the characteristics and typical applications of abrasives used in wet blasting.

Table 30-5-8

Characteristics and Typical Applications of Abrasives Used in Wet Blasting



Abrasive	Size, mesh	Characteristics and applications
Silica	40 to 80	Fast-cutting. Used for deburring steel and cast iron, removing oxides from steel. Close tolerances cannot be held.
Silica	80	Fast-cutting. Used for deburring steel and cast iron, roughening surfaces for plastic bonding or rough plating. Has peening action. Tolerances cannot be held.
Quartz (ground)	80	Very fast-cutting. Used for removing heavy burrs, light or medium scale, excessive rust. Can be used on nickel alloy steels. Tolerances cannot be held.
Novaculite	100	Fast-cutting. Used for cleaning carbon from piston and valve heads; deburring brass, bronze and copper. Can be used on crankshafts. Tolerances cannot be held.
Quartz (ground)	100, 140	Fast-cutting. Used for blending-in preliminary grind lines on steel, brass and die castings; removing medium-hard carbon deposits; blasting radii of 0.005 to 0.010 in.
Silica	140	Used for removing small burrs from steel, copper, aluminum and die castings; rough cleaning of dies and tools; removing metal. Tolerances cannot be held.
Novaculite	325	Slow-cutting. Used in first stage for cleaning master rods and glass, and in second stage for cleaning aluminum pistons, crankshafts, impellers, valves. Holds tolerances to 0.0025 in.
Aluminum oxide	400	Fast-cutting. Used on stainless steel and on zinc and aluminum die castings. Excellent for oil-contaminated surfaces.
Novaculite	1250	Used in second stage for cleaning crankshafts, impellers, rods, pistons, valves, gears and bearings. Also for polishing metals, tools, dies and die castings. Tolerances can be held.
Novaculite	5000	Used for obtaining extra-fine surfaces on parts.
Bright shot (glass beads)	20 to 400	Used for removing light scale or discoloration after heat treating, removing light oxide from jet-engine and electronic components. Produces peening effect.

The health hazard associated with blast cleaning is silicosis. Silicosis is a disease of the lungs that results from the prolonged breathing of very fine particles of silica. The effects of silicosis can be permanently disabling and even fatal. A common practice is to have the blaster personnel x-rayed prior to employment and at least once a year thereafter. The films should be read by a physician specializing in this particular field.

Sand blasting of sand-free steel or iron castings and shot blasting of sandy castings produce enough fine silica to make the air dangerous to breathe. Blaster personnel are protected by a helmet supplied with air, special gauntlets, an apron, and special spats. The air supplied to blaster personnel is approximately 6 cubic feet per minute, clear, odorless, dry, and free from gaseous contaminants.

Salt Bath Descaling

Salt bath descaling processes are affective in removing tight-adhering scale from nickel-base alloys, cobalt-base alloys, and some grades of stainless steel. The process is classified as reducing, oxidizing, or electrolytic.

The reducing process of salt bath descaling consists of immersing the workpiece in a molten sodium hydroxide bath containing 1.5 to 2.0% sodium hydride. Sodium hydride descaling involves the chemical reduction of metal oxides to the metallic state or to lower oxides. The reduced material is then readily removed from the work by a water quench followed, when required, by appropriate acid dips.

Workpieces are immersed and held in the bath until the reducing action on the scale has ceased. Treatment duration is dependent upon the type of base metal and the type and amount of scale. Duration may range from a few seconds to 20 minutes. Upon completion of the reducing cycle, the workpiece is removed from the bath, allowed to drain for a short period, and quenched in water. Varying amounts of reduced scale are "blasted" from the surface, exposing base metal, during the quenching phase. Subsequent to quenching, the workpiece is immersed in acid solutions, followed by water rinsing, producing a bright, clean metal surface.

In the oxidizing process, sodium hydroxide, in conjunction with various other oxidizing salts, performs an active function in the carrier bath, unlike its function in the reducing process. Varying according to different proprietory formulations, the ratio of salts and types of oxidizing agents is typically represented by (1) 60% to 90% sodium hydroxide, (2) 7% to 32% sodium nitrate, and (3) 1.5% to 6% sodium chloride. The preferred operating temperature is approximately 900°F although the temperature may range from

800 to 1000°F.

Scale consists of both lower and higher oxides. When a scaled workpiece is immersed in an oxidizing salt bath, both the metal and the scale are heated to operating temperature. However, the unequal expansion rates of the metal and scale result in the cracking of the scale. The salt penetrates the cracks and oxidizes the lower oxides to form soluble salts and water. This reaction disrupts the physical dimension of the scale and causes the scale to become soft and porous.

A violent activity occurs when the workpiece is quenched. Steam causes the scale cracks to open further. A portion of the scale is rinsed away while the remainder is loosened and conditioned for rapid removal by pickling or acid dipping.

An electrolytic salt bath is designed principally for continuous operation although it may be used as a batch-type process. In the continuous operation for cleaning strips, two tanks, each insulated from the other, contain baths of similar concentrations of sodium hydroxide, sodium chloride plus sodium fluoride, and sodium carbonate. The bath temperatures are maintained at 900°F. Continuously, the strip is passed from a gas-fired annealing furnace through the two electrolytic descaling tanks. A direct current passes from cathodic grids to the strip in the first tank. In the second tank, the current passes from the strip to anodic grids. The strip is passed on to pickling, scrubbing and drying equipment from the second tank. The salt action is neutral until current is applied. The salt oxidizes the scale as the strip becomes positive in the first tank. As the strip becomes negative in the second tank, the salt and the evolution of hydrogen gas remove the higher oxides from the strip.

Compared with acid pickling or mechanical descaling methods, salt bath descaling offers several advantages although it also has disadvantages. Its advantages include (1) Extended range of alloys that can be effectively descaled, (2) more efficient removal of scale from surface discontinuities, (3) Shorter time for descaling of all grades of stainless steel, (4) more uniform surface finish by eliminating the pitting and localized etching that result from the selective action of pickling acid at scale breaks, (5) virtual elimination of metal loss (which can amount to 1 to 3% in acid pickling), (6) elimination of hydrogen embrittlement of steel, and minimization of embrittlement caused by acid pickling, through reduction of acid treating requirements, and (7) less destructive than mechanical descaling to smooth finishes. Its disadvantages include (1) high operating temperatures, (2) distortion of relatively thin-gage materials (0.032 in. and less), (3) increased maintenance cost, (4) electrolytic pitting and possible ignition of titanium and its alloys, and (5) ineffective in removing heavier scale (such as that on hot rolled, box annealed strip) in the time afforded by continuous strip processing.

For any operation involving fused salts at 700-1000°F, safety precautions must be observed during the use and servicing of salt bath descaling equipment. Extreme care must be taken to prevent water from coming in contact with the bath and with metallic sodium. A violent reaction takes place and molten caustic will splatter when contacted by water. Workpieces must be thoroughly dry prior to immersion in a salt descaling bath. Magnesium and magnesium alloys must not be used in salt descaling baths as they will burn. Workpieces entering the bath must also be free of cyanide or a violent reaction will occur.

Alkaline Cleaning

Oily, semisolid and solid soils are removed by alkaline cleaning methods. Alkaline cleaning is employed to prepare metallic surfaces for electroplating, conversion coating, or otherwise finished or processed. The solutions used in alkaline cleaning depend upon their detersive properties for cleaning action and effectiveness. An alkaline is a solution which has a pH greater than 7.

The effectiveness of alkaline cleaners is attributed mainly to the action of "builders", the bulk components of alkaline formulations. The common builders employed are carbonates, phosphates, silicates and hydroxide.

Carbonates serve as buffers, as sources of alkalinity, and as water softeners. The carbonates are poor cleaners, but they supply a fair amount of alkalinity (a 1% aqueous solution, for example, gives a pH of 11.5). However, the real value of carbonates is in helping to keep compounded cleaners dry and free-flowing. This is especially important for cleaners containing a large amount of sodium hydroxide.

Phosphates, such as trisodium phosphate, tetrasodium pyrophosphate and sodium tripolyphosphate also have some* sequestering properties.

Silicates make up the largest portion of most heavy-duty alkaline soak cleaners. Sodium orthosilicate, sodium metasilicate, and sodium sesquisilicate are excellent emulsifiers, are good buffers at pH above 9, hold soils in suspension, and provide active alkalinity.

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* Sequestrant - A material that combines with metal ions to form water-soluble complex compounds.

Sodium hydroxide (caustic soda) is inexpensive and is often the principal builder for supplying the necessary alkalinity. In addition, it increases electrical conductivity of the solution and improves saponification. However, its detergent ability is very poor for the nonsaponifiable soils, and it has the poorest rinsing properties of all the common builders.

Surface-acting (wetting) agents are added to alkaline cleaning solutions to lower surface and interfacial tensions and, therefore, to enhance the cleaning action of the cleaner. The surface-acting agents are composed of soaps and synthetic detergents, commonly called syndets.

Sodium resinate, a by-product of the kraft papermaking process, is an extensively used soap. Several grades of sodium resinate are commercially available. Higher grades are more costly, as a result of their refining, but produce only slightly better cleaning than the middle grades. The low grades contain a fairly high content of unsaponified fatty acids, which form insoluble calcium, magnesium and iron soaps with hard water. They should be used with a water-softening agent. In small amounts, resinate soaps do not lower surface and interfacial tensions as much as synthetic detergent. However, resinates emulsify certain soils more easily than do the syndets, thereby justifying their use in alkaline cleaners. Most soak cleaners contain both resinates and syndets.

Synthetic detergents are extensively used as surface-active agents because they are freer-rinsing than soaps, aid soil dispersion, and prevent resoiling. They are effective in softening hard water and in lowering surface and interfacial tensions. In addition, the syndets are less susceptible than soaps to contamination by acid residues. Two types of syndets, anionics and nonionics, are commonly used. The usual concentration range is

0.01% to 1.0% active. The anionics generally are the least expensive of the syndets, and when in solution produce abundant suds. Alkyl aryl sodium sulfonate is the most extensively used anionic. The nonionics usually produce less suds than the anionics. The nonionics most commonly used are sulfonated esters and ethers, and those of the polyoxyethylene type. The latter is a combination of ethylene oxide condensed on a base such as polyoxypropylene. Lower percentages of ethylene oxide make the substance hydrophobic, increasing its solubility in oil; higher percentages increase its solubility in water (make it hydrophilic) and also increase its foaming properties. Table 30-5-9 lists the typical alkaline cleaner formulations employed for cleaning various metals

Table 30-5-9

Typical Alkaline Cleaner Formulations for Various Metals

	Aluminum		Copper			Cu plate	Iron and steel			Magnesium		Zinc		
	Soak	Spray	Soak	Spray	Electrolytic	Electrolytic	Soak	Spray	Electrolytic	Soak	Spray	Soak	Spray	Electrolytic
Composition of Cleaner, % by Weight														
Builders:														
Sodium hydroxide, ground	...	...	20	15	15	55	20	20	55	20	20	...	15	15
Sodium carbonate, dense	...	...	18	...	...	8	18	29	8.5	18	29	...	...	...
Sodium bicarbonate	21	24	...	34	34	...	...	...	...	...	...	...	35	34
Sodium tripolyphosphate	30	30	...	...	10	...	20	20	10	20	20	90	10	10
Tetrasodium pyrophosphate	...	...	20	10	...	10	...	...	...	...	...	...	...	...
Sodium metasilicate, anhydrous	45	45	30	40	40	25	30	30	25	30	30	...	40	40
Surface-active (wetting) agents:														
Sodium resinate	...	...	5	...	...	...	5	...	...	5	...	5	...	...
Alkyl aryl sodium sulfonate	3	...	5	...	...	...	5	...	1	5	...	5	...	...
Alkyl aryl polyether alcohol	...	...	2	...	...	1	2	...	...	2	...	...	...	...
Nonionics high in ethylene oxide	1	1	...	1	1	1	...	1	0.5	...	1	...	...	1
Other Conditions														
Operating temperature of solution, F	160	160	180	170	180	180	200	170	180	200	170	180	170	180
Concentration of cleaner, oz/gal H_2O	4	1	8	1	8	6	8	1	8	8	1	4	1	6
Relative cost of chemicals(a)	136	121	148	102	104	118	150	107	111	150	107	194	100	104

(a) The cost index is based on the lowest-cost formulation (spray zinc) as 100. The base value of 100 corresponds to a cost of $4 to $8 per 100 lb of the cleaner formulation depending on quantity and local purchasing conditions

Periodic tests must be made on alkaline solutions to control solution strength. Acid soils, hard water, sludge resulting from ion absorption and dilution resulting from water additions weaken alkaline cleaners. Solution strength is determined by the titration method of chemical analysis.

In this method, a control test is made by titrating 0.1 N (N = Normal) hydrochloric acid in a 25 milliliter sample of the solution to a phenolphthalen end point. A duplicate test is performed on a fresh solution of cleaner of the desired point. Comparison of the result indicates the amount of replenishment required to bring the process solution to desired strength.

The double titration method of alkaline solution strength determination is dependent on a chemical titration for equivalent hydroxide and equivalent carbonate. Neutralization is accomplished with a known concentration of hydrochloric acid. The hydroxide is neutralized, and the carbonate is converted to bicarbonate, at an approximate pH of 8.5 (phenolphthalein). Methyl orange is added, and the titration is continued until the bicarbonate is neutralized (pH - 3.8).

The values for the acid concentration, expressed as normality (n), and milliliters of acid used to titrate to each end point are required to determine the concentration of hydroxide and carbonate. If the first end point is A and the second B, both expressed in milliliters, then for this acid-base reaction, N acid X milliliters acid = N base X milliliters base. The only unknown is N base. The volume of acid solution used to neutralize the hydroxide is A-(B-A). The volume of acid used to neutralize the carbonate is 2(B-A).

For a 1N solution of sodium hydroxide, there is 40 g per liter of solution, or 5.35 oz per gal. For a 1N solution of sodium carbonate, there is 53 g per liter, or 7.06 oz per gal. For a 10-ml sample of cleaner, the concentration of the two is derived from these formulas:

$$\text{Oz per gal } N_2CO_3 = \frac{2(B-A) \times N \text{ acid} \times 7.06}{10}$$

$$\text{Oz per gal NaOH} = \frac{[A-(B-A)] \times N \text{ acid} \times 5.35}{10}$$

$$\text{Total oz per gal} = \text{Oz per gal } Na_2CO_3 + \text{Oz per gal NaOH}$$

Figure 30-5-2. Titration Calculation

A double end point will exist for cleaner solutions made up of other alkalis or containing other alkaline materials. However, the titration does not sort out the constituents. To test for other alkalis, make a liter of solution of the desired strength. As above, titrate a 10 milliliter sample. Calculate the result as though the sodium carbonate and hydroxide were actually present. The calculated ounces per gallon of total cleaner will not be the same as the actual concentration of as-made cleaner, except in the case of sodium carbonate and sodium hydroxide. To find a factor to be used in further titrations of the cleaner in production, divide the as-made concentration by the total as-calculated concentration.

$$f = \text{FACTOR} = \frac{\text{As-Made Concentration (X)}}{\text{As-Calculated Concentration (Y)}} \qquad \text{Formula 30-5-1}$$

For operation, therefore, f times Y equals the cleaner concentration in the production tank.

The difference, in ounces per gallon, between the hydroxide and the carbonate, along with the total amount of cleaner is important for control of the alkaline cleaning process. More equivalent hydroxide is indicated by a large positive difference. This solution composition is normally a harsher cleaner on nonferrous alloys.

In spray washers, the solution balance can be upset due to carbon dioxide reacting with sodium hydroxide and other alkaline materials. At a lower pH, other cleaner materials will hydrolyze or transpose. Additions of sodium hydroxide may counteract the change in cleaner balance.

Experience must be gained in correlating the results of analysis with those of the cleaning process. The double-titration method provides a means of controlling solution strength and reducing consumption of the cleaner. When the cleaner is performing unsatisfactorily, yet the phenolphthalein indicator shows the solution to be in proper specification range, a more complete analysis must be made and/or the solution must be replaced.

The principal methods employed in alkaline cleaning are soak, spray, and electrolytic. The efficiency of soak cleaning, as compared to spray and electrolytic, is limited unless the soil is easily removable. Soak cleaning is generally employed for moderate or small volumes of work. Table 30-5-10 illustrates the basic cycles employed in soak, spray, and electrolytic alkaline cleaning.

The spray method of alkaline cleaning is more effective for removing tenacious soils than the soak method. The advantages of the detersive properties of the solution and the impinging action of the spray are combined in spray cleaning. Spray cleaners have lower detersive properties than soak cleaners because of foaming problems.

The most efficient method of alkaline cleaning is the electrolytic method. The strong agitation of the bath by gas evolution and the oxidation-reduction reactions during electrolysis combine to establish the effectiveness of this cleaning method. Another important factor in electrolytic cleaning is that similar electrical charges are imparted to certain dirt particles and to the workpiece causing the dirt to be repelled from the work surface.

Table 30-5-10

Basic Alkaline Cleaning Cycles

Variable	Cleaning method Soak	 Spray	 Electrolytic
Cleaning			
Time, minutes	3 - 5	½ - 1	½ - 1
Temperature, F	160 - 212	130 - 170	160 - 210(b)
Conc, oz/gal	4 - 8(c)	½ - 1½	4 - 8(c)
Unheated Rinsing			
Time, minutes	¼ - ½	To ½	¼ - ½
Temperature, F	Ambient	Ambient	Ambient
Hot Rinsing			
Time, minutes	½ - 2	To ½	½ - 2
Temperature, F	160 - 220	130 - 160	160 - 200
Hot-Air Drying			
Time, minutes	1 - 3	½ - 1	1 - 3
Temperature, F	160 - 220	160 - 220	160 - 220

(a) Usually preceeded by soak or spray cleaning. (b) Electrocleaners are seldom operated below 180 F. (c) This may be increased to as much as 12 oz/gal for some severe applications with soak and electrolytic cleaners.

CLEANNESS CONTROL ACTIVITIES

Introduction

Cleanness control activities are planned and outlined by the owner or by direction of the owner to define cleaning and inspection operations to be used during construction and operations phases of nuclear power plants. The principal objective of these activities is to maintain cleanness of supplied items during installation activities of the construction phase and during maintenance and modification activities of the operations phase. One or more of the cleaning methods described by Part I of this module is used only as necessary and whenever unacceptable soils are introduced.

In order to meet the principal objective, cleanness control activities include cleanness classification, pre-installation cleanness installation cleaning, maintenance of installation cleanness, preoperational cleaning, layup, and housekeeping.

Cleanness Classification

The degree of required cleanness is a function of the particular system under consideration. The owner of the nuclear power plant is responsible for establishing the cleanness classification of each system. These classifications consider the susceptibility to corrosion, the consequences of malfunction or failure, and the probability of contaminants contributing to or causing such malfunction or failure. Cleanness classifications are specified on design drawings and associated specifications. Procurement documents specify internal component cleanness requirements consistent with the requirements of the system for which the component is intended. American National Standard, ANSI N45.2.1, describes four cleanness classifications, all components of the system must meet the acceptance criteria associated with the level of classification.

- Class A Cleanness - The highest cleanness classification level is Class A. Class A is a very high level of cleanness in which there is no evidence of contamination of a component surface. The method of evaluation of Class A cleanness is visual, with or without magnification, or with the aide of sensitive detection methods. Class A cleanness applies to special items such as fuel elements, control rod drive mechanisms, and delicate instruments. Class A components receive their required level of cleanness at the point of manufacture and cleanness is maintained at the construction site.
- Class B Cleanness - Class B cleanness is a high level of cleanness applicable to reactor coolant systems, components and other items such as the reactor coolant purification system. Piping and components in systems which require Class B cleanness must meet the following requirements:
- The surface must appear "metal clean" when examined without magnification under a lighting level (background plus supplementary lighting) of at least 100 foot candles. Scattered areas of rust are permissible provided the aggregate area of rust does not exceed 2 square inches in any one square foot area. (Localized rusting may indicate pitting of the surface and is evaluated metallurgically . Thin temper films resulting from welding or post-weld heat treatments are acceptable.)
- The surface must be free of particulate contaminants such as sand, metal chips, weld slag, etc.
- The surface must be free of organic films and contaminants such as oils, paint, and preservatives as

determined by a visual examination or an organic solvent-dampened white cloth or an equivalent alternate method.

- When a visual inspection is not possible and the surfaces are accessible, a dry white-cloth wipe, followed by a solvent-dampened white-cloth wipe, may be used to evaluate the cleanness of the surface. If either cloth exhibits indications of contamination, the system is recleaned or the specific contaminant is determined and evaluated as to its potential deleterious effect.
- If flushing is the only practical means for determining system cleanliness, the system is evaluated by examining a 20-mesh (ASTM E11-70, Specifications for Wire Cloth Sieves for Testing Purposes) or finer filter, or the equivalent, installed on the outlet of the cleaning circuit. The system is flushed at its normal design velocity (or other velocity if specified by procurement documents) until the screen shows no more than slight particle speckling and no more than slight rust staining. There must not be particles larger than 1/32 inch thickness in any dimension, except fine hairline slivers of less than 1/32 inch thickness are permissible up to 1/16 long. There must not be evidence of organic contamination in the effluent water or on the filter.
- Class C Cleanness - Class C cleanness is an intermediate level of cleanness generally applicable to closed service-water systems that cool components containing reactor coolant, engineered safety systems, and other high integrity systems. Class C Cleanness requires the surfaces to meet the requirements established under Class B cleanness with the

exception of the following:

- Thin uniform rust films are acceptable on carbon steel surfaces.
- Scattered areas of rust are permissible provided that the area of rust does not exceed 15 square inches in any 1 square foot on corrosion resistant alloys.
- Flush-test filters may exhibit considerable rust staining.
- Class D Cleanness - The least stringent cleanness requirements are those established for Class D cleanness. Class D cleanness is applicable to fire-protection, open service water, and similar systems requiring only a nominal degree of cleanness. The following are acceptable on items which meet Class D cleanness:
- Tightly adherent mill scale on carbon steel surfaces.
- Paint or preservative coating on carbon steel surfaces that will not peel or flake when exposed to cold-water flushing.
- Rust films on carbon steel and stainless steel surfaces that resist removal by scrubbing with a bristle brush.
- If flushing is the only practical means of determining system cleanness, the system must be evaluated by examining a 14-mesh or finer filter, or the equivalent, installed on the outlet of the cleaning circuit. The system must be flushed at its normal velocity until the screen shows no more than occasional particle speckling. There must not be particles larger than 1/16 inch in any dimension, except hairlike slivers of less than 1/16 inch thickness are permissible up to 1/8 inch long. There must not be evidence of organic contamination on the screen; considerable rust-staining is acceptable.

Preinstallation Cleanness

Prior to initial installation of components and prior to replacement of components or use of repair parts, the cleanness of the item is determined by inspection. Acceptance criteria is that for the cleanness classification of the system for which the item is intended. Failure to meet the applicable acceptance criteria results in cleaning the item with a method suitable for the soils involved. In this manner, construction, maintenance, or modification activities start with an acceptably clean component or part. The following steps are typically taken by the owner to ensure availability of clean components:

- procurement documents specify the cleanness classification to be met by the component at time of shipment to the plant site by the component supplier.
- procurement documents specify the level of packing and packaging of components in transient to protect the item from physical damage and to maintain its cleanness.
- delivery to the construction site is delayed, where possible, until shortly before the item is to be installed.
- receipt inspection is performed to verify compliance with cleanness classification.
- on-site storage facilities are equipped to maintain cleanness of the item.
- the item is inspected for cleanness at time of use.

With the above controls in place, cleaning of received components is normally unnecessary except for one special condition, i.e., temporary preservatives. Some components, such as carbon steel fasteners, are sometimes protected from atmospheric corrosion by temporary coatings of grease, paint, or other preservative. Such temporary coatings are removed shortly before use of the component. A cleaning method is selected based on the type of preservative to be removed.

Installation Cleaning

Installation activities (construction, repair, modification) represent opportunities for introducing contaminants into a clean item. These activities are controlled in order to minimize the contamination of cleaned items and to perform cleaning operations as necessary as installation progresses. Typical controls consist of good work practices, sealing openings, prohibition of deleterious materials, and cleaning at completion of the work.

- work practices - Operations which have potential for contaminating components include welding, grinding, sanding, chipping, wire brushing, sawing, painting, and grit blasting. These operations can internally contaminate the affected component or adjacent components. Highest potential for contamination exists when there are exposed crevices, blind holes, dead legs, undrainable cavities, and inaccessible areas. In such cases, work practices are planned to avoid contaminating the components. These practices include:
- orientation of the work such that chips, spray, or other contaminants fall away from the area of concern.
- temporarily covering areas of concern with tarpaulins or other protective materials.
- masking areas of concern.
- sealing - Aside from temporary sealing of openings during performance of a particular installation activity, openings in components and pipe ends are sealed at all times except when the specific work activity requires removal of the seals. In addition, fitted weld joints, which are not immediately welded,

are wrapped in polyethylene or other non-halogenated plastic until welding is performed. These sealing practices ensure protection from internal contamination regardless of the nature of work in the vicinity.

- prohibition of deleterious materials - Corrosion resistant alloys (stainless steel and nickel base alloys) are susceptable to stress corrosion cracking when subjected to stress, temperature, and low melting alloys or halogens. By avoiding contamination with low melting alloys and halogens, stress corrosion cracking is avoided. Accordingly, low melting alloys and halogens are prohibited from use during installation activities. This means that marking materials, seals, hammers, paints, preservatives, and other materials used on corrosion resistant alloys cannot contain the prohibited materials. Such items are procured and certified as acceptable based on their not containing low melting alloys such as lead, sulfur, zinc, and mercury, and not containing leachable halogens. In this manner, contact of corrosion resistant alloys with deleterious materials is avoided.
- cleaning at completion of installation - Installation activities consist of a number of "work segments" with each segment constituting a desired and manageable increment of work. A "job package" is prepared for each segment. The job package contains necessary instructions, drawings, and procedures to accomplish the work. The final step of the instructions for each job package requires leaving the installation in an acceptably clean condition. At this step, soils introduced by the work are removed by an acceptable cleaning method and seals are placed on openings and pipe ends. In this manner, components are left

in the prescribed cleanness condition and protected from future contamination.

Maintenance of Installation Cleanness

After each component and piping system is installed, some time may elapse prior to connecting all openings with their interfacing components or piping. As previously described, installed components and piping systems are left clean and sealed by the installation activity. Two basic controls are used to ensure such cleaned and sealed items remain clean. First, the quality control activity periodically monitors for integrity of seals and for compliance of work activities with the instructions of the job package. Second, job packages for work activities which require opening of installed seals contain special instructions for maintaining cleanness. Typically, these special instructions include (1) cleaning of the surrounding area prior to opening a seal, (2) clean outer clothing and shoe covers for personnel who must enter the cleaned system, (3) recleaning interior surfaces upon completion of the work, and (4) resealing remaining openings and pipe ends.

Preoperational Cleaning

Preoperational cleaning ensures that a system is in a specified state of cleanness prior to designating that system as ready for operation. Preoperational cleaning is accomplished by flushing the system with water or a cleaning solution, dependent upon the degree of cleaning activities during installation activities. If each installation activity complied with the cleaning and cleanness controls previously described, water flushing is sufficient. However, if internal surfaces were not cleaned and maintained clean, flushing with a cleaning solution is necessary. Flushing with a cleaning solution is followed by a water flush to remove the cleaning solution. It is typically more economical to control cleanness of large components and large diameter piping during installation such that only a water flush of the installed system is necessary. Two principle sources of contamination which may require flushing with a cleaning solution are oil from air tools and oxide films on internal surfaces in systems which require removal of internal rust.

Each type of flushing requires specific preparations for accomplishing the flush. In this regard, consideration is given to other plant activities, personnel readiness, circulating flow paths, component protection, and water quality.

- other plant activities - Cleaning and flushing operations are scheduled to minimize interference from other plant operations. Either installation activities or tests of other system may require use or isolation of the system to be flushed. In such instances, flushing is delayed until a "time window" exists where the system is dedicated to the flushing activity. During the flush, coordination with installation activities is necessary to preclude violation of cleanness of the system by nearby installation activities.
- personnel readiness - Flushing is typically the first activity which operates the system as a whole. Personnel must be familiar with system operation and location of system components and control devices. In addition, whenever cleaning agents are used, personnel must be familiar with the use and associated safety precautions of the cleaning agent. Finally, personnel must be familiar with the flushing procedure. Training of personnel in these areas is conducted in advance of flushing operations to

permit timely accomplishment of flushing within the alloted "time window".

- circulating flow paths - The actual flow path of the flush is carefully established and checked to ensure adequate flushing. This is normally accomplished by the preparer and reviewer of the flushing procedure. The established flow path must be consistent with requirements of system specifications. Dead legs (such as vent, drain, and instrumentation lines) are identified and special provision is made for their flushing. All components and component controls which must not be actuated during the flush are identified and tagged. Tags are normally red in color and state "Danger - Do Not Operate".
- component protection - Components which may be damaged by the flush are blanked off, bypassed, or removed. Examples of such components are demineralizers, filters, certain instruments, and internals of certain valves. Screens are installed on pump suctions. Ideally, all systems are flushed prior to installing reactor internals and control rods. But in the event flushing is necessary after installation of reactor internals, flushing is either away from the reactor vessel or particulate filters are installed. Finally, provisions are made to collect leakage and the flushing discharge in order to prevent wetting of thermal insulation and electrical components.
- water quality - An ample supply of water of necessary quality must be on hand for water flushing or for flushing to remove cleaning agents. The quality of the flushing water is required to equal the quality required for system operation. Where system operating water quality is not specified, engineering

selects either "fresh water" or "demineralized water: for the flush. (demineralized water is equivalent to that specified for reactor coolant systems). Water quality limits for fresh and demineralized water are listed in Table 30-5-11.

Table 30-5-11. Water Quality Requirements

Element	Water	
	Fresh	Demineralized
pH at 25°C	5.5 to 8	5.5 to 8
Chloride	< 100 ppm	< 1 ppm
Fluoride	< 5 ppm	< 1 ppm
Sulfide	< 1 ppm	< 1 ppm
Total Dissolved Solids	< 500 ppm	not applicable
Turbidity	< 5 Jackson Units	< 1 Jackson Unit
Silica	not applicable	< .05 ppm
Conductivity	not applicable	< 3 μmho/cm

Each flushing operation is performed in accordance with a written procedure or instruction. Flushing may be with water, alkaline cleaning solutions or chelating agents as necessary.

Flushing with water is typically adequate if the intended level of cleanness was maintained during installation. Key elements of water flushing are (1) confirmation of completion of necessary preparations, (2) use of water of required quality, (3) velocity of flush equal to system design velocity or other specified value, (4) provision for acceptance of flushing by filter, turbidimetric, or chemical analysis, (5) provision for flushing dead legs upon completion of the system flush, and (6) provision for system sealing or layup after the flush.

Flushing with alkaline cleaning solutions is used when systems are known or suspected to contain oil residues or other organic soils not readily removable by water flushing. Alkaline cleaners, such as trisodium phosphate, are selected which do not contain free caustic. Emulsifiers and wetting agents may also be used if heavy organic soils are present. Key elements of alkaline cleaning flushes are (1) confirmation of completion of necessary preparations, (2) use of specified cleaner and concentration, (3) heating of the alkaline cleaning solution to the specified temperature, (4) provision for determining adequacy of cleaning (typical methods are examination of a known soiled area or use of a test coupon contaminated with the expected soils), (5) water flushing upon completion of alkaline cleaning including flushing of dead legs, and (6) provision for sealing the system or placing it in layup.

Flushing with chelating agents is used when light corrosion product films must be removed from carbon and low alloy steels. However, this method is not suitable for sensitized stainless steel or nickel base alloys. (Sensitization of stainless steel refers to chromium-carbide precipitation to grain boundaries. Acid cleaning attacks carbides). In addition, entrapment of acids in crevices and contact of acids with nonferrous materials is avoided. Key elements of chelate cleaning are (1) confirmation of completion of necessary preparation, (2) use of specified acid-chelate solution, (3) complete removal of the acid-chelate solution by draining, water flushing, and a neutralization flush, and (4) system sealing or layup.

Layup

Upon completion of preoperational cleaning, the system may be released for preoperational testing such as hydrostatic testing. In such event, the next test takes control of the system and its condition. However, the cleaned system may rest idle for some time period prior to preoperational testing. In such event, the system is placed in layup.

Layup is a condition in which an idle system is placed to protect that system from oxidation and entry of contaminants. It maintains system cleanness subsequent to preoperational cleaning.

Either dry or wet layup is used. Dry layup is the condition obtained by filling the system with a dry, inert gas. Either nitrogen or the system operating gas for gas systems are used. Wet layup is the condition obtained by filling with water of specified quality or with the operating liquid for liquid systems.

For either dry or wet layup, initial filling includes venting of all high points to remove air. Also, the system is moderately pressurized and system pressure is monitored to maintain the layup condition.

When water is used for wet layup, chemical treatment is normally made to control pH and to scavenge dissolved oxygen. Hydrazine-morpholine treatments are common where hydrazine scavenges oxygen and morpholine controls pH. Where treated water is used, periodic tests are made to determine the need for chemical additions. Also, at the conclusion of the layup period, the treated water is drained and the system is filled with its operating fluid.

Housekeeping

Integral with the foregoing activities, housekeeping procedures are established at the nuclear power plant site to control the general cleanness of designated areas within the plant. Housekeeping procedures define area zones and establish controls within each type of zone for controlling cleanness. Five types of zones are established as follows:

- Zone I - Zone I Areas require the highest order of cleanness. These areas are equipped with a clean clothing change facility at the vestibule or entrance, preferably with toilet facilities immediately adjacent so that personnel working in the controlled area do not have to wear the special clothing in other areas. Such areas provide for complete outer change of clothing by personnel, including use of shoe covers, head covers, and gloves to protect all equipment surfaces from outside contamination. Material entering this zone is appropriately cleaned prior to entry.
- Zone II - Zone II Areas have intermediate cleanness requirements less restrictive than Zone I but are areas where foreign matter may have detrimental effects.
- Zone III - Zone III Areas are less restrictive than Zones I and II but require access control over personnel and materials.
- Zone IV - Zone IV Areas are those where it is desired to regulate the use of tobacco and eating for material and equipment protection or for health and fire hazards.
- Zone V - Zone V Areas are unrestricted construction areas requiring good construction site housekeeping practices only.

For each type of area, written procedures delineate the responsibilities and techniques for maintaining cleanness at the desired level. For Zones I, II and II, the procedures require a written record (e.g., logbook) of the entry and exit of all personnel and material. In general, these procedures require the elements of control listed in Table 30-5-12.

Table 30-5-12

Control Elements for Housekeeping Zones

Element	Zones				
	I	II	III	IV	V
Clothing change	Yes	No	No	No	No
Clean gloves, shoe covers, head covering	Yes	Yes	No	No	No
Filtered air	Yes	No	No	No	No
Material precleaning	Yes	No	No	No	No
Material accountability	Yes	Yes	Yes	No	No
Personnel accountability	Yes	Yes	Yes	No	No
No use of tobacco or eating	Yes	Yes	Yes	Yes	No

GLOSSARY OF TERMS

- Acid Cleaning - The removal of metal oxides by either dissolution of the oxide or undercutting the oxide by dissolution of the base metal with an acid solution.
- Alkaline Cleaning - The removal of organic contaminants by converting them to an emulsion with an alkaline solution such as trisodium phosphate.
- Chelate Cleaning - The removal of slightly soluble compounds such as iron oxide, by complexing the metallic ions with organic chelating compounds such as ethylene diamine tetra-acetic acid (EDTA).
- Chemical Conditioning - The addition of chemicals in low concentration to flush, rinse, or layup water to prevent precipitation of dissolved solids, inhibit corrosion, etc.
- Cleaning - The removal of any contaminants that might have a deleterious effect on plant safety and

reliable operation.

- Contractor - Any individual or organization entering into a contract to furnish items or services to a purchaser. The term contractor includes the terms Vendor, Supplier, and Subcontractor or sub-tier levels of these where appropriate.
- Contamination - Any undesirable foreign material on the surface of an item, in the atmosphere, or in process liquids or gases.
- Corrosion Resistant Alloys - Materials, such as stainless steel, nickel-base, or cobalt-base alloys, that inherently resist oxidation or chemical attack in water, air, and the operating environment.
- Crevice - Any narrow opening in a surface or any open juncture between mating surfaces in which solutions can be trapped and not readily removed during rinsing or flushing operations; for example, the annular spaces in threaded connections and socket assemblies, tube-to-tube sheet joints, and tube-to-tube support joints.
- Dead Leg - Any area that does not have flow during the cleaning operation or which cannot be drained without special provisions.
- Documentation - Any written or pictorial information describing, defining, specifying, reporting or certifying activities, requirements, procedures or results.
- Flushing - Flowing water through a component or system at adequate velocity to suspend and carry away anticipated contaminants.
- Inhibitor - A chemical additive which retards some specific chemical reaction.
- Inaccessible Area - An area or opening in an item which is not directly accessible for cleaning or inspection.

- Item - Any level of unit assembly, including structure, system, subsystem, subassembly, component, part or material.
- Layup - The protection of an item after it has been cleaned, to prevent corrosion of interior surfaces while the item is out of service or awaiting subsequent operations.
- Mechanical Cleaning - A method in which contaminant removal is accomplished solely by mechanical means, including wiping, abrasive blasting, brushing, grinding, sanding, chipping, etc.
- Pitting - Localized corrosion resulting in surface defects.
- Purchaser - The agency responsible for issuance and administration of a contract, subcontract, or purchase order imposing a standard or portions thereof.
- Rinsing - (1) Filling and draining an item with water until contaminants in the effluent water are reduced to some predetermined concentration, or (2) flowing water through the system or component at low velocity until contaminants in the effluent water are reduced to some predetermined concentration.
- Rust - Corrosion products, consisting largely of iron oxide. Such oxides may vary in color from red to black and may form a loosely adherent heavy covering to a tightly adherent light film. Pitting or general surface roughening may or may not be present.
- Sensitized Corrosion Resistant Alloy - Any alloy which has been subjected to heating that causes intergranular precipitation of chromium carbides in quantities sufficient to be detected by methods of ASTM A262-68, Recommended Practices for Detecting Susceptibility to Intergranular Attack in Stainless Steel.
- Solvent Cleaning - Dissolving organic contaminants with an organic solvent.

EXERCISES

This check list summarizes the major points of this module. Put a check by each point as you recall it.

____ Solvent cleaning is a process for removing organic soils with an organic solvent. The cleaning method may be by wiping, immersion or spraying, with or without vibration of the part. It is typically used for smaller parts and for hand cleaning of large parts.

____ Emulsion cleaning is a process for removing organic soils with an emulsified solvent-aqueous medium. It is mostly used by suppliers when superficial cleaning is sufficient and when a light film of residual oil is desired or not objectionable.

____ Acid cleaning is a process for removing inorganic and organic soils with an acid. Inhibitors are used to reduce the amount of attack on metals and for spray systems, antifoaming agents are added to reduce foaming. Methods of acid cleaning include wipe on-wipe off, spraying, immersion, barrel, and electrolytic. Any acid cleaning process etches the part to some degree. It is generally used when inorganic soils must be thoroughly removed.

____ Acid pickling is a more severe acid cleaning process. It uses immersion techniques and is most efficient for removal of scale. It is generally used when bright metallic finish is required.

____ Chelating is a form of acid cleaning which uses chelating agents. Chelates accelerate cleaning of lubricants containing metallic ingredients by reacting with the metal ions. It is generally used for cleaning of piping systems.

____ Vapor degreasing is a cleaning process which uses hot vapors from a chlorinated solvent to remove organic soils. Four methods are available: vapor phase, vapor-spray-vapor, warm liquid-vapor and boiling liquid warm liquid-vapor. Ultrasonic vibration may be used for small parts. It is generally used for cleaning oily parts, particularly those with crevices.

____ Abrasive blast cleaning is a method of removing organic and inorganic soils by the forceful impingement of abrasive particles against a surface. Dry or wet blasting techniques are available. Some peening and cutting of the surface occurs with abrasive blasting. It is generally used for removing scales and coatings.

____ Salt bath descaling is a method of removing tight-adhering scale from nickel and cobalt base alloys. It may use reducing, oxidizing, or electrolytic processes. It is generally used by material suppliers to clean final material forms.

____ Alkaline cleaning is a method of removing organic and inorganic soils by detergent cleaning. Soak, spray, or electrolytic processes may be used. It is generally used by material and component suppliers for removing oily soils and light rusts.

____ Component cleanness acceptance criteria is that associated with the cleanness classification of the system which receives the component. Four classification levels are established.

____ Cleanness classification levels and their associated acceptance criteria are:

Classification	Acceptance Criteria
Class A	No evidence of contamination
Class B	Clean appearance except for scattered rust, no particulate contaminants, no organic films or contaminants, acceptable to cloth wipe or flushing filter tests.

Class C	Same as Class B except that surfaces may have thin uniform rust films on carbon steel, scattered areas of rust on corrosion assistant alloys, and rust staining on flushing filters.
Class D	Nominal cleanness. Acceptable conditions are tightly adherant scale on carbon steel, coatings without flaking or peeling, adherent rust films, and acceptable flushing test results.

____ Preinstallation cleanness controls ensure that components to be installed are clean. Procurement documents specify the cleanness conditions to be met by materials and product. Receipt inspection confirms compliance and storage facilities maintain cleanness. Temporary preservatives are not removed until shortly before installation of the item.

____ Installation cleaning activities minimize introduction of soils and accomplishes necessary cleaning operations as installation progresses. Installation cleaning activities include work practices which foster cleanness, use of seals, prohibition of deleterious materials and cleaning operations as necessary at completion of installation.

____ Maintenance of installation cleaning preserves the established degree of cleanness. Between installation and flushing, cleanness of components and systems is maintained by seals and special controls when seals must be opened. The special controls include cleaning the surrounding area, use of protective clothing, recleaning interior surfaces upon completion of work and resealing.

____ Preoperational cleaning is accomplished by water flushing unless soils are present which require other cleaning methods. When other cleaning is necessary, alkaline flushing is mostly used although acid-chelating agent flushing may be necessary to remove rust films.

____ Specific preparations are necessary for flushing. These preparations include scheduling a "time window", training personnel, establishing the flushing paths and component protective measures to be used, and ensuring availability of ample water of necessary quality.

____ Alkaline or chelate flushing is followed by water flushing to remove the cleaning agents.

____ Unless the system is released to other tests, each system is placed in layup after flushing. Layup means filling the system with its operating fluid or with water or nitrogen. Wet layup with water normally includes chemical treatments to control pH and to scavenge oxygen. Hydrazine is used to scavenge oxygen and morpholine is used to control pH.

____ Housekeeping refers to the establishment of area zones, cleanliness requirements for each zone and procedures for entry and exit of persons and material.

MATERIALS

The following materials are required to support this module if the optional activities for turbidity and titration-analyses are used:

1. Jackson Candle Turbidimeter Kit
2. Plastic tubing
3. Rubber bulb siphon

4. Assorted beakers
5. One or more sources of water
6. Distilled water
7. Laboratory reagents of sodium hydroxide, sulfuric acid and any other acid.
8. Assorted burettes
9. Burette stands and clamps
10. Glass stirring rods

PROCEDURES

The following activities reinforce the information presented in this module:

1. Determine if the acceptance criteria as given by this module, have been met. For each of the following product descriptions, list each condition of noncompliance and a method of cleaning which will remove each condition of noncompliance.
   a. Receipt inspection examines carbon steel flanged pipes and elbows destined for a Class C system. The faces of five flanges exhibit light rust which is partially removed by light brushing. Interior walls appear clean except for rust films which are not removable by brushing. Eighteen of the flange through holes (for bolting) exhibit rust which is flaking.

b. Preoperational water flushing of a Class B stainless steel system exhibits the following upon first inspection of the flushing filter: no rust staining, three minute particles of about 1/64 inch diameter, a paper strip 1 by 2 inches, four metallic slivers the smallest of which is 1/32 inch width by 1/4 inch long.

c. A six inch motor operated carbon steel gate valve is withdrawn from site stores for installation into a Class C system. Visual Inspection determines that a tight rust film is exhibited throughout the valve internals. In addition, a spot of loose rust measuring 1/2 by 1 inch is found on the weld and preparation on the inlet nozzle.

d. A 1/2 inch stainless steel manual globe valve is withdrawn from site stores for installation into a Class B system. Visual inspection reveals: lint on the inside diameters of inlet and outlet nozzles and oil residue adjacent the seat.

e. A Class C system is flushed with water. Initial inspection of the flushing filter exhibits rust spackling and considerable oil stains. No particulates other than rust spackling are present.

f. A length of carbon steel pipe is visually inspected upon receipt. The pipe is intended for the fire main header. Interior surfaces of the pipe exhibit flaking scale.

g. A visual inspector enters a storage tank of a Class B system after installation and flushing of the tank. The inspector observes: metallic chips, in the bottom of the tank, adherent discolorations on each welded joint, and six areas of loose rust. The areas of rust are widely separated and measure 1/2 x 1, 1/2 x 2, 2 x 2, 1 x 2, 1 x 3, and 1/4 x 1/2 inches.

2. Perform a Jackson Turbidity Test (Optional Activity)
   a. Assemble the following equipment: (1) Jackson Candle Turbidimeter (consists of graduated glass tube, a standard candle, a light shield around the tube, and a support for the candle and tube), (2) plastic tube and rubber bulb siphon, (3) assorted beakers, (4) sample water for test from one or more sources.
   b. Mount the turbidimeter in the vertical position such that the centerline of the graduated tube passes through the centerline of the candle.
   c. Darken the room for all observations.
   d. Enclose the graduated tube with its light shield.
   e. Light the candle and pour sample water into the graduated tube until the candle flame is no longer visible.
   f. Siphon sample water from the graduated tube until the candle flame becomes visible.
   g. Extinguish the candle flame.

h. Read the Jackson turbidity units at the level of the sample.

3. Perform a Titration Method of chemical analysis (Optional Activity):
   a. Prepare a dilute solution of sodium hydroxide by adding 30 milliliters of the laboratory reagent to 120 milliliters of distilled water. Mix thoroughly by stirring. Do not contaminate or dilute this solution in any way as it will be used throughout this experiment.
   b. Obtain two burettes from the instructor, one for the acid and one for the base. Rinse both burettes twice with water.
   c. Drain the water and rinse one of the burettes with two small portions of the sodium hydroxide solution you have prepared. Fill the burette with sodium hydroxide solution.
   d. Obtain 100 milliliters of a standard solution of sulfuric acid from the instructor. The normality of this solution will be given to you.
   e. Rinse, drain, and fill the second burette in the same manner with the acid solution.
   f. Clamp the burettes to the burette stand and fill the tip of each burette by opening the stopcock momentarily and letting a small amount of the solution flow through the tip into the beaker containing that solution.
   g. Read the level of the solution in each burette by lining your eye with the bottom of the miniscus. Read the burette to the nearest 0.01 milliliter. Record these values on the data sheet.
   h. To standardize the base solution, draw approximately 15 milliliters of the standard acid solution into a small beaker.

i. Add 2 drops of phenophthalein solution to the acid.

j. While constantly stirring, slowly add approximately 3 to 4 milliliters of the base from the burette.

   Note: As the base hits the acid, a red color forms, but disappears quickly on stirring. To make the color change easier to see, place a piece of white paper under the beaker.

k. With constant stirring, slowly add more base solution until one drop produces a permanent pink color in the solution. This color should persist for at least 30 seconds.

   Note: If too much base is accidentally added, add more acid until the solution is again colorless. Titrate again until one drop produces the permanent pink color change.

l. To insure that none of the solution has adhered to the sides of the beaker and the stirring rod, wash them down with distilled water using a wash bottle.

m. Read the burettes. Record the readings on the data sheet.

   Note: Wait about one minute prior to taking the burette readings to allow for any drainage in the burettes.

n. Repeat steps of the experiment starting with about 20 milliliters of acid. Record burette reading on the Data Sheet. From the data obtained, calculate the normality of the base you prepared. Record calculations on Data Sheet. (milliliters of base) (Normality of base) = (milliliters of acid) (Normality of acid) Use this formula for your calculations.

o. Obtain, from the instructor, an unknown acid solution whose concentration you are to determine.

The base you prepared and standardized is to be used as the standard solution in this titration. Record the data as before on the data sheet. Calculate the Normality of the unknown. Be sure to record the number of your unknown.

p. Give data sheet to instructor

DATA TABLE

Table 30-5-13

Data Sheet for Titration

	Standard Acid	Base
Final Burette Reading	__________ml	__________ml
Initial Burette Reading	__________ml	__________ml
Volume of Solution	__________ml	__________ml
Final Burette Reading	__________ml	__________ml
Initial Burette Reading	__________ml	__________ml
Volume of Solution	__________ml	__________ml

Normality of NaOH Solutions Run#1 __________N Run#2 __________N

Unknown Sample

	Standard Base	Acid
Final Burette Reading	__________ml	__________ml
Initial Burette Reading	__________ml	__________ml
Volume of Solution	__________ml	__________ml
Final Burette Reading	__________ml	__________ml
Initial Burette Reading	__________ml	__________ml
Volume of Solution	__________ml	__________ml

Normality of Unknown Acid Solution Run #1__________N Run #2__________N

Average__________N

Number of Unknown Sample________________

Instructor Review__________________________ Date______________

Calculations

REFERENCE MATERIALS

NRC, Regulatory Guide 1.37, Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water Cooled Nuclear Power Plants, Nuclear Regulatory Commission, Washington, D.C., 1973

NRC, Regulatory Guide, 1.39, Housekeeping Requirements for Water Cooled Nuclear Power Plants, Nuclear Regulatory Commission, Washington, D.C., 1977

ASME, ANSI N45.2.1, Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants, American Society of Mechanical Engineers, New York, N.Y., 9173

ASME, ANSI N45.2.3, Housekeeping During the Construction Phase of Nuclear Power Plants, American Society of Mechanical Engineers, New York, N.Y., 1973

ASM, Metals Handbook, Volume 2, American Society for Metals, Metals Park, Ohio, 1964

ASTM, Annual Book of ASTM Standards, Part 31, American Society for Testing and Materials, Philadelphia, PA 19103, 1978

TEST

1. Briefly describing the following cleaning methods including the types of soils removed and its general application.
   a. Solvent Cleaning

   b. Emulsion Cleaning

   c. Acid Cleaning

   d. Acid Pickling

   e. Chelating

   f. Vapor Degreasing

   g. Abrasive blast cleaning

   h. Salt Bath Descaling

   i. Alkaline Cleaning

2. Define:
   a. cleaning

   b. contamination

   c. crevice

   d. dead leg

   e. flushing

   f. inaccessible area

   g. layup

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3. Name four cleanness classification levels and briefly describe the degree of cleanness associated with each level.

Classification	Degree of Cleanness
a.	
b.	
c.	
d.	

4. State the purpose of each of the following cleanness control activities.
   a. Preinstallation cleanness

   b. Installation cleaning

   c. Maintenance of installation-cleaning

   d. Preoperational cleaning

   e. Layup

   f. Housekeeping

5. Briefly describe how each of the following cleanness control activities is accomplished.
    a. Installation cleaning

    b. Preoperational cleaning

    c. Wet layup

6. Briefly describe typical preparations for flushing which are associated with:
    a. other plant activities

    b. circulating flow paths

    c. component protection

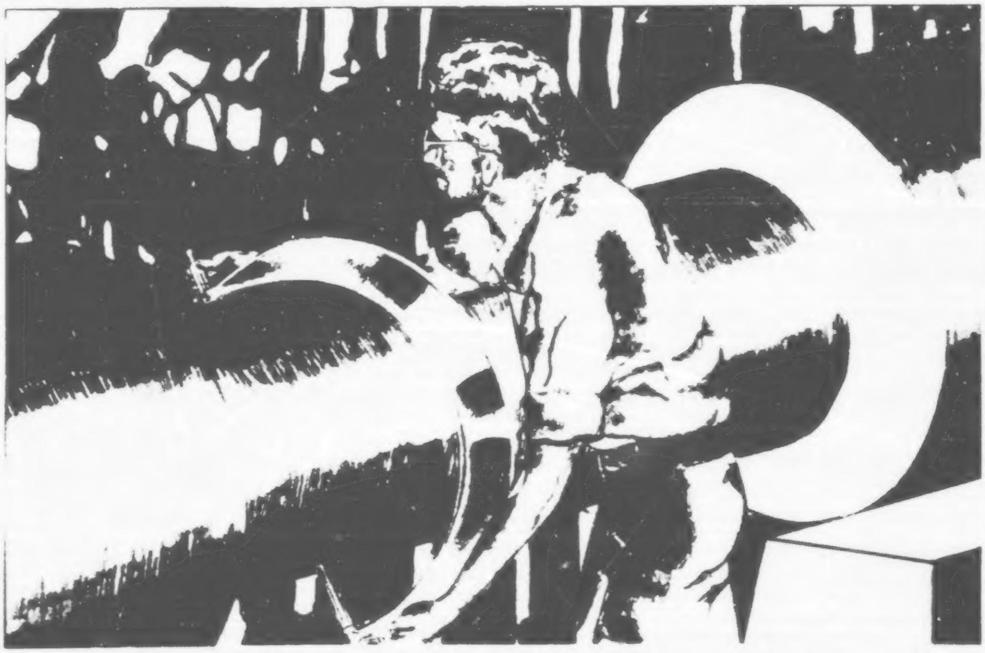
    c. water quality

7. Describe typical water treatment used for wet layup.

NUCLEAR TECHNOLOGY

MODULE 30-6

PROTECTIVE COATING INSPECTION



COURSE 30 MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
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COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

MODULE 30-1	Pump Inspection
MODULE 30-2	Pump Functional Testing
MODULE 30-3	Valve Inspection
MODULE 30-4	Piping Inspection
MODULE 30-5	Sufrace Cleaning Inspection
⇨ MODULE 30-6	Protective Coating Inspection
MODULE 30-7	Pressure Vessel Inspection
MODULE 30-8	Rotating Equipment Inspection

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INTRODUCTION

The Nuclear QA/QC Technician typically has three duties associated with protective coatings. This module presents information to support the performance of these duties which are (1) assuring that qualified paints are used, (2) assuring that proper techniques are employed for application of protective coatings, and (3) inspecting coating thickness and condition.

The term "protective coating" is applied to a wide variety of surface coatings intended to protect the coated surface. Such coatings are typically named for their method of application which includes anodizing, phosphatizing, aluminizing, plating, oxidizing, chromating, cementizing, and painting. Each of these types of coatings can be found to some extent in various parts and components which comprize the nuclear power plant. These coatings are typically applied by the suppliers of the items. However, this module pertains to paints used for protective coatings for nuclear reactor containment facilities.

During the construction phase, protective coatings (paints) are applied within the nuclear reactor containment building for the reasons described by this module. Typical facilities which receive the protective coating are:

- containment structures and shells
- spent fuel carriers
- underwater storage pools and operating equipment
- fuel dismantling areas
- decontamination areas
- maintenance areas
- chemical makeup areas
- off-gas and filtration systems
- solid and liquid waste disposal systems
- water storage tanks

National standards govern the selection, application and inspection of protective coatings for the reactor containment systems. This module describes the quality assurance provisions of these standards: ANSI N5.9, Protective Coatings (Paints) for the Nuclear Industry; ANSI N101.2, Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities; and ANSI N101.4, Quality Assurance for Protective Coatings Applied to Nuclear Facilities.

MODULE PREREQUISITES

All previous modules in this course must have been completed before proceeding to this module.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Define the terms substrate, coating system, run, sag and holiday.
2. State two purposes of protective coatings.
3. State the purpose of qualification of coating materials and describe the relationship of Design Basis Accident to such qualification.
4. State the general purpose of Dynamic Elevated Temperature - Pressure Tests, Irradiation Tests and Contamination - Decontamination Tests.
5. Differentiate between Near-White Blast Cleaned Surface Finish and Commercial Blast Cleaned Surface Finish.
6. Describe the controls placed on coating materials

including supplier's certification, labeling, and sample retention.

7. State the primary purpose of preparation of surfaces of substrates.
8. State three examples of environmental conditions which typically must be controlled during surface preparation of substrates and name three control measures which may be used.
9. Describe the importance of controlling and removing contaminants during surface preparation of substrates.
10. Name five topics which must be addressed by the coating contractor's application procedures.
11. Name four phases of coating work which are inspected by the inspection agency.
12. State the purpose of reports issued by the inspection agency including daily inspection report, nonconformance report, and acceptance report.
13. Describe how to make wet film thickness measurements by the quantity method and by use of fixed gages.
14. Describe the contribution of wet film thickness measurements to the coating system.
15. Describe the principle of operation of dry film thickness measurement gages.
16. Name the type of inspection used and its primary objective when given an element of coating inspection programs.
17. Describe the operation of nondestructive holiday detectors.
18. Calculate dry film thickness when given data on volume of paint used, percent solids, and surface area coated.

SUBJECT MATTER

FUNDAMENTALS

Purpose of Protective Coatings

Protective coatings (paints) serve two primary purposes with respect to reactor containment facilities. These purposes are (1) to protect surfaces from corrosion, and (2) to provide a surface which can be decontaminated.

Engineering may stipulate that surfaces be coated to satisfy either or both purposes. Corrosion protection is provided by prevention of contact of the coated surface with its environment. In addition, primers and paints may be selected which provide cathodic protection or include reactive pigments which set up conditions that impede corrosion. Decontamination capability is provided by the ability to clean the surface of the coating. Such capability becomes increasingly important with the potential accumulation of radioactive material during the 40 year plant life. Also, in the event of an inadvertant leakage of radioactive materials into containment, coated surfaces are much more easily decontaminated.

Basic Terms

A glossary of terms is provided at the end of this module. The student/trainee should refer to the glossary as new terms are encountered. The QA/QC Technician is mostly concerned with the terms substrate, film thickness and those which name defective conditions.

Substrate is the uncoated surface which is to be coated. Regardless of the type of material, e.g., concrete, steel, aluminum, the surface to be coated is termed the substrate. Film thickness is divided into wet-film thickness and dry film thickness. Wet-film thickness is the depth of applied coating immediately after application.

Dry-film thickness is the depth of applied coating when dry.

Wet and dry film thicknesses are expressed in "mils". A mil is equal to 0.001 inch. For example, a 5 mil thickness is equal to 0.005 inch.

Relationship to Design Basis Accident

Reactor design provides for reasonable assurance that the facility can be operated without undue risk to the health and safety of the public. Design processes include the analysis of the ability of safety related systems to prevent or mitigate the consequences of postulated accidents. Such postulated accidents are termed Design Basis Accident (DBA) and establish the environment which protective coatings would see if such an accident occurs.

The environment within containment during a DBA is characterized by steam-air atmospheres at elevated temperature, pressure, and ionizing radiation. Also, water sprays, with or without chemical additives are present. Protective coatings must resist deterioration from such an environment. For this reason, coatings are qualified by a series of tests which simulate the environment of a DBA. Only qualified coatings are used for coating systems.

Qualification Tests

The designer determines the tests necessary for qualifying the coatings to be used in containment. Sample panels of substrates are coated and subjected to the specified tests. Satisfactory performance of the coating as revealed by test results qualifies the coating. That particular brand and type of coating remains qualified provided the supplier does not change formulation such that coating properties substantially change. Typical tests are identified in Table 30-6-1.

Table 30-6-1

QUALIFICATION TESTS		
TESTS	GENERAL PURPOSE	GOVERNING STANDARD
Flame Spread Test	Determine the flame spread rating of the coating. Coating must not be major fire hazard.	ASTM E84, Standard Method of Test for Surface Burning Characteristics of Building Materials.
Thermal Conductivity Test	Develop thermal conductivity data for use in consideration of heat capacity of containment structures in the analysis of DBA.	Appendix A to ANSI N101.2 or ASTM D2214, Tentative Method of Test for Thermal Conductivity Constant with the Cenco-Fitch Apparatus.
Dynamic Elevated Temperature-Pressure Test	Determine the performance of the coating system under DBA environments including water immersion, water spray, vapor, temperature, pressure, and chemicals as predicted by design analysis of DBA.	ANSI N101.2, Protective Coatings for Light Water Nuclear Reactor Containment Facilities.
Irradiation Test	Determine the performance of the coating system when subjected to the integrated radiation dose anticipated during DBA.	ANSI N5.9, Protective Coatings(Paints) for the Nuclear Industry.
Contamination-Decontamination Test	To provide a quantitative evaluation of the ease and the degree of contamination and decontamination of protective coatings.	ANSI N5.9, Protective Coatings (Paints) for the Nuclear Industry.
Chemical-Resistance Tests	To provide a quantitative evaluation of the resistance of protective coatings to chemical environments.	ANSI N5.9, Protective Coatings (Paints) for the Nuclear Industry.
Physical Property Tests	To provide a quantitative evaluation of the physical properties of protective coatings including hardness, abrasion, adhesion, impact resistance, weathering, and flexibility.	ANSI N5.9, Protective Coatings (Paints) for the Nuclear Industry.

The test panels subjected to the dynamic elevated temperature-pressure and irradiation tests are inspected shortly after completion of the tests and again two weeks later. Acceptance criteria are typically no flaking, no delamination or peeling, few intact blisters, and no heavy chalking. Compliance with the acceptance criteria demonstrates that the particular coating will perform satisfactorily if it is subjected to DBA conditions.

Surface Preparation Requirements

For each type of surface to be coated, the project specification stipulates the requirements to be met by the surface of the substrate immediately prior to application of coating. Typical requirements for the substrates of carbon steel, aluminum, galvanized steel, stainless steel, and concrete and masonry surfaces are listed in Table 30-6-2. Descriptions of the grades of surface preparations applicable to carbon steel are contained in Table 30-6-3.

Table 30-6-2

TYPICAL SURFACE PREPARATION REQUIREMENTS

SUBSTRATE	TYPICAL REQUIREMENTS
Carbon Steel	For surfaces which under DBA are immersed or continuously exposed to steam or frequently exposed to strong chemicals: - NACE No. 2 or equivalent (see Table 30-6-3) - Welds free from sharp projections and blend smoothly into base metal - All weld spatter removed. - All loose foreign material removed - Crevices, gouges, and joints filled with material compatible with substrate and coating system. - Dry surfaces For surfaces which under DBA are subject to occasional splash, spillage, or exposure to strong decontamination materials: - NACE No. 3 or equivalent - All loose foreign material removed - Crevices, gouges, and joints filled with material compatible with substrate and coating system - Dry surfaces For surfaces supplied with primer applied: - Removal of foreign materials with appropriate cleaning method such as detergents or solvents.
Aluminum	For surfaces which under DBA are immersed: - All welds continuous, free from sharp projections, and blended smoothly into base metal - All weld spatter removed - Uniform surface profile compatible with coating system - Surface clean and dry For surfaces which under DBA are not immersed: - All loose foreign material removed - Crevices, gouges and joints filled with material compatible with substrate and coating system - Surface profile compatible with coating system.
Galvanized Steel	- Solvent cleaned and degreased - Crevices, gouges and joints filled with material compatible with substrate and coating system
Stainless Steel	- Cleaned and degreased - For surfaces under DBA to be immersed or frequently exposed to strong chemicals, abrasive blasting to provide a compatible profile. - Clean and dry
Concrete and Masonry	- Clean and dry - Water stain, grout accumulations, sealing compounds, form release agents and other impurities removed. - For concrete surfaces, breaking open hollow areas, air pits, and holes with a material compatible with the substrate and coating system. - For masonry surfaces such as concrete blocks, fill with a material compatible with the substrate and coating system.

Table 30-6-3

GRADES OF SURFACE PREPARATION

GRADE	DESCRIPTION
NACE No. 1 White Metal Blast Cleaned Surface Finish	Defined as a surface with a gray-white (uniform metallic) color, slightly roughened to form a suitable anchor pattern for coatings. This surface is free of all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, and other foreign matter. (Comparable to SSPC-SP 5-63, White Metal Blast Cleaning)
NACE No. 2 Near-White Blast Cleaned Surface Finish	Defined as a surface from which all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, or other foreign matter have been removed except for light shadows, streaks, or slight discolorations (of oxide bonded with metal). At least 95% of any given surface area has the appearance of NACE No. 1, and the remainder of that area is limited to slight discolorations. (Comparable to SSPC-SP 10-63T, Near-White Blast Cleaning).
NACE No. 3 Commercial Blast Cleaned Surface Finish	Defined as surface from which all oil, grease, dirt, rust scale, and foreign matter have been completely removed and all rust, mill scale, and old paint have been removed except for slight shadows, streaks, or discolorations caused by rust stain or mill scale oxide binder. At least two-thirds of the surface area shall be free of all visible residues and the remainder shall be limited to light discoloration, slight staining, or light residues mentioned above. If the surface is pitted, slight residues of rust or paint are found in the bottom of pits. (Comparable to SSPC-SP 6-63, Commercial Blast Cleaning).
NACE No. 4 Brush-off Blast Cleaned Surface Finish	Defined as a surface from which oil, grease, dirt, loose rust scale, loose mill scale, and loose paint are removed, but tightly adhering mill scale, rust, paint and coatings are permitted to remain if they have been exposed to the abrasive blast pattern, so that numerous flecks of the underlying metal are uniformly distributed over the entire surface. (Comparable to SSPC-SP 7-63, Brush-Off Blast Cleaning).

ELEMENTS OF QUALITY ASSURANCE FOR PROTECTIVE COATINGS

Five Elements

The nuclear plant owner, or agency thereof, stipulates in a project specification the areas to be coated and the requirements to be met by the coating materials, coating contractor, and inspection agency. The quality assurance program addresses five elements to ensure compliance with the project specification:

- Coating materials
- Surface preparation of substrate
- Application of coating systems
- Coating inspection
- Documentation.

Coating Materials

The quality assurance program ensures use of qualified coating materials. In order to provide such assurance, provisions are made for control of manufacturing of the coating, identification of delivered coatings, labeling, sample retention, performance verification tests, and documentation.

Control of manufacturing is stipulated in procurement documents. The manufacturer of qualified coatings is required to maintain a quality assurance program which documents that the quality of the coating is reasonably identical to that qualified. The program must ensure requalification if there are significant changes in formulation or end-product properties.

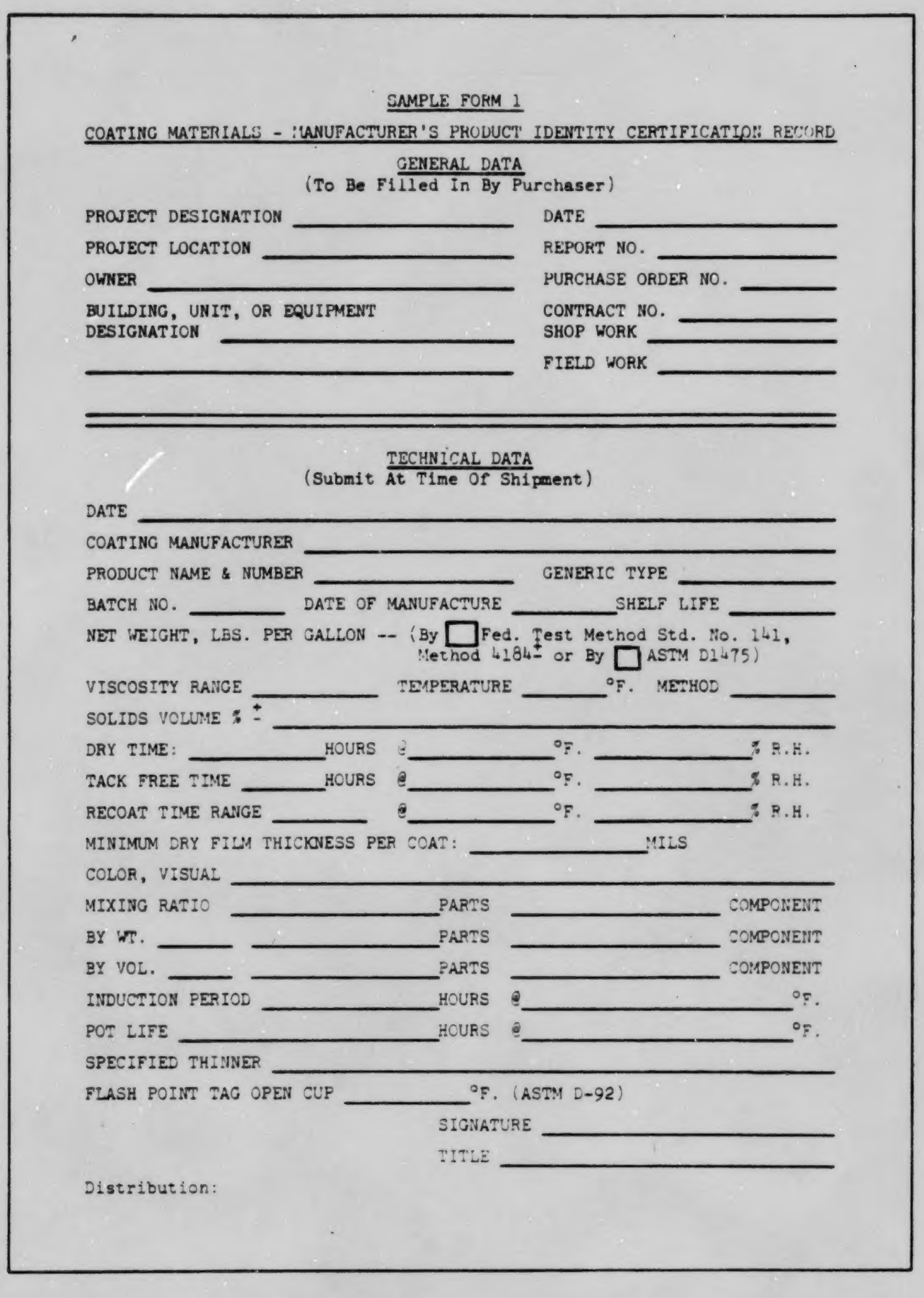
Product identity consists of certification by the manufacturer that the product identity of the materials being supplied meet the requirements of the project specification. Such certification is required for each batch of materials and may be made on the form illustrated by Figure 30-6-1. As described later, product identity is verified at receipt and maintained during use of coating materials.

Labeling of each container is required. Each label identifies the product designation, batch number, and date of manufacture, as a minimum. The product designation and batch number permit association of the manufacturer's certification record with a specific container. The date of manufacture provides the starting point in time for which the shelf life applies.

Sample retention from each batch is required. The coating manufacture retains batch samples for either two years or the shelf life whichever is shorter. This provides the capability to test each batch as may be necessary to resolve disputes on the quality of the materials.

Performance verification tests when required, provide additional assurance of the quality of the materials. The plant owner may require, in the project specification, that specific tests be conducted on the coating materials to be used. These tests may be any of the qualification tests and, when they are required, must be accomplished prior to release of the materials for application. When such tests are required, the owner specifies the exact tests to be performed, what agency is responsible for conducting the tests, the size and number of specimens and their preparation, and provisions for the owner to witness test specimen preparation and conduct of tests.

The minimum documentation with respect to coating materials are the manufacturer's certification and material control records established by the owner and the applicator. The manufacturer's certification attests to the quality of the supplied materials. The owner's and applicator's



SAMPLE FORM 1

COATING MATERIALS - MANUFACTURER'S PRODUCT IDENTITY CERTIFICATION RECORD

GENERAL DATA

(To Be Filled In By Purchaser)

PROJECT DESIGNATION ____________ DATE ____________

PROJECT LOCATION ____________ REPORT NO. ____________

OWNER ____________ PURCHASE ORDER NO. ____________

BUILDING, UNIT, OR EQUIPMENT DESIGNATION ____________ CONTRACT NO. ____________

SHOP WORK ____________

FIELD WORK ____________

TECHNICAL DATA

(Submit At Time Of Shipment)

DATE ____________

COATING MANUFACTURER ____________

PRODUCT NAME & NUMBER ____________ GENERIC TYPE ____________

BATCH NO. ________ DATE OF MANUFACTURE ________ SHELF LIFE ________

NET WEIGHT, LBS. PER GALLON -- (By ☐ Fed. Test Method Std. No. 141, Method 4184± or By ☐ ASTM D1475)

VISCOSITY RANGE ________ TEMPERATURE ________ °F. METHOD ________

SOLIDS VOLUME % ± ____________

DRY TIME: ________ HOURS @ ________ °F. ________ % R.H.

TACK FREE TIME ________ HOURS @ ________ °F. ________ % R.H.

RECOAT TIME RANGE ________ @ ________ °F. ________ % R.H.

MINIMUM DRY FILM THICKNESS PER COAT: ________ MILS

COLOR, VISUAL ____________

MIXING RATIO ________ PARTS ________ COMPONENT

BY WT. ____ ________ PARTS ________ COMPONENT

BY VOL. ____ ________ PARTS ________ COMPONENT

INDUCTION PERIOD ________ HOURS @ ________ °F.

POT LIFE ________ HOURS @ ________ °F.

SPECIFIED THINNER ____________

FLASH POINT TAG OPEN CUP ________ °F. (ASTM D-92)

SIGNATURE ____________

TITLE ____________

Distribution:

Figure 30-6-1. Manufacturer's Product Identity Certification Form Recommended by ANSI N101.4.

material control records provide evidence that the certified materials were in fact used.

Surface Preparation of Substrates

Surface preparation of substrates is a major factor in the ability to obtain an acceptable protective coating. It has been estimated that 2/3 of the application costs are necessarily associated with surface preparation of substrates. You may have personal experience with adverse painting results caused by inadequate preparation of substrates.

Surface preparation of substrates has the objective of providing adequate adhesion of the coating system to the substrate. The cleanness and profile of the surface are important to accomplishing this objective. In this regard, this element of the quality assurance program addresses conformance with specified requirements, control measures for ambient conditions, removal of contaminants, and documentation.

The coating applicator is responsible for compliance with the requirements for surface preparation of each substrate as specified by the project specification. Typical requirements are those listed previously in Table 30-6-2.

Control measures are typically necessary for ambient conditions. The cleaning process used to prepare substrate and the prepared surface prior to coating may be adversely affected by environmental conditions such as temperature, humidity, and air-born contaminants such as chemical vapors. The project specification stipulates the necessary environmental controls applicable to surface preparation. The coating contractor is responsible for determining that stipulated conditions are met and, if they are not met, arranging with the owner for execution of control measures.

The control measures, such as heating, cooling, ventilating, and humidity control, must be maintained until the coating is applied. The inspection agency monitors for compliance with these requirements.

The project specification stipulates the control and removal of contaminants which might interfere with application, adhesion, curing, or performance of the coating system. Whether the source of contaminants is the cleaning process or other adjacent construction activities, controls are applied. Compliance with requirements are monitored by the inspection agency. Typically, requirements are necessary to accomplish the following:

- Control and removal of all blasting abrasives, grit, and dust.
- Control of welding fumes and removal of subsequent contaminants.
- Removal of welding scale and spatter.
- Removal of pickling residues.
- Removal of cement spatter, laitance, and mortar.
- Removal of incompatible form-release agents and membrane curing compounds.
- Removal of all other deleterious matter.

The coating contractor is responsible for documenting the surface preparation of substrates. Typically, daily reports are made which identify method of surface preparation, anchor pattern obtained, removal of contaminants, environmental conditions and curing agents used, if any.

Application of Coating Systems

The coating contractor is required to use written procedures for the application of each coating system on each type of substrate. These procedures are typically subject to approval by the owner and the coating supplier. The procedures describe the practices which will be used by the coating contractor in the following areas:

- Qualification of application personnel
- Receiving, storage, handling, and dispersing coating materials.
- Application equipment
- Application parameters such as environmental conditions, regulation of equipment, ventilation, cleanliness, viscosity, viscosity control, film thickness control, number of coats, curing time, and other pertinent factors.
- Field preparation of coating material such as mixing, thinning, and activating.
- Health, safety, and fire protection requirements.
- Instruments and their use for measuring relative humidity, temperature, viscosity, wet and dry film thickness, and holidays.
- Documentation.

The application equipment and techniques described by the applicator's procedures must be compatible with the project specification and the coating supplier's recommendations for the specific coating material. Qualification of application personnel is based on the documented experience of each person. The documentation must include the basis of personnel qualification, daily reports, and material control records associated with the receipt, storage, handling, and dispensing of coating materials.

Coating Inspection

The owner, or agent thereof, is responsible for inspection of coatings and is termed the inspection agency. The inspection agency is responsible for carrying out inspections of all phases of the coating work. Such inspection is typically performed and reported for the following phases:

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- Adequacy of facilities and equipment for storage, mixing, and application.
- Receipt of coating materials
- Substrate before surface preparation
- Substrate following surface preparation
- Application of each coat while wet and the film characteristics after drying.

Inspection personnel must be qualified. The quality assurance program of the inspection agency must describe the training and experience which serves as the basis for qualification. In general, the inspector must be knowledgeable of coating materials and application techniques through training and field experience in quality control of coating applications.

The inspection agency documents results of inspections. Typically, three types of records are completed as follows:

- Daily inspection reports which describe the materials, controls, and environmental conditions being used by the applicator.
- Deviation report which identifies deviations from specified requirements and recommends corrective actions.
- Acceptance inspection report which documents the acceptance of a coating system. This report is based on final inspection and satisfactory completion of the other two records.

Documentation

This element of the quality assurance program applies to the coating material supplier, the coating applicator, the inspection agency and the owner. Typical documentation has been described earlier in this module and is summarized in Table 30-6-4.

Table 30-6-4

QUALITY ASSURANCE DOCUMENTATION FOR COATINGS

Responsible Organization	Documentation
Coating Manufacturer	Product Identity Certification
Coating Purchaser	Receiving and storage records
Coating Applicator	Coating materials handling records Surface preparation record Painter qualification record Coating record Touchup record
Inspection Agency	Inspector qualification record Daily inspection report Nonconformance report Coating system acceptance record
Owner	Coating system acceptance record

COATING INSPECTION TECHNIQUES

Coating inspections determine that requirements of the project specification are met and that nonconformances are corrected as required. Inspection determines that there is strict adherence to procedures by the applicator and that coating results meet specified requirements. This is necessary because paint provides the intended protection only when it is properly applied and when proper film thickness and integrity are obtained.

In the early stages of contracting for coating work, the power plant owner arranges for inspection services. Either the owner's quality control department or a contracted agency may serve as the inspection agency. In either case, an agreement is documented on the extent of inspections to be performed, the acceptance criteria for inspection results, and responsibilities for the correction of noncompliances. The agreement provides for the qualification of inspectors and serves as the quality control program for the inspection agency.

Coating inspections consist of record reviews, visual inspections and inspections with special gages. The elements typically inspected, the type of inspection, and the desired objective are listed in Table 30-6-5

Inspection of Substrates

Visual inspections confirm that surface preparation of substrates meets requirements of the project specification. These inspections typically determine compliance with requirements for the following characteristics:

- moisture in/on concrete or steel substrates
- contaminants on concrete substrates such as form-release agents, membrane curing compounds, or other

Table 30-6-5

ELEMENTS OF COATING INSPECTION PROGRAMS

Element	Type of Inspection	Inspection Objective
Coating Materials	Record Review	Supplier's product identity certification is adequate
	Visual	Type, quantity, color, condition, and packaging meets requirements.
Storage	Visual	Applicator uses storage conditions as recommended by coating material supplier.
Equipment	Visual	Mixing, application and safety equipment meet specified requirements and are in good operating order.
Safety	Visual	Specified safety precautions are met during the storage, mixing, handling, and application of coating materials.
Substrates	Visual	Specified requirements for surface preparation of substrates are met.
Environment	Visual and gages such as thermometers and hygrometers	Specified environmental controls are met.
Thinning	Visual	Type and quantity of thinner recommended by coating material supplier are used.
Application, Film thickness, and Film appearance.	Visual and special gages	Specified requirements for each coat are met for coating material, appearance, thickness, and workmanship.

deleterious matter.

- surface condition of concrete substrates and the remedial work required.
- contaminants on steel substrates such as pickling residues or other deleterious matter.
- anchor pattern on steel substrates
- surface temperature of substrates.

Wet Film Thickness Inspection

Wet film thickness is measured in order to determine that dry film thickness requirements will be met. There is a definite relationship among volume of paint applied per square area, wet film thickness, and dry film thickness.

A gallon container of paint can be pictured as having a film thickness equal to the height of the container over an area equal to that of the base of the container. It follows that if the height is reduced by one-half, the area of the base must increase by a factor of two in order to accommodate a one gallon volume. This relationship applied to coating thickness results in one gallon occupying approximately 1600 square feet at a thickness of one mil. At a thickness of two mils, one gallon occupies approximately 800 square feet. This relationship applies to wet film thickness and is theoretically expressed by the following formula:

$$T_W = \frac{1600G}{A} \qquad \text{Formula 30-6-1}$$

where:

T_W = wet film thickness in mils
G = volume of paint used in gallons
A - area in square feet covered by gallons used

Wet film gages provide a quicker measurement of wet film thickness. These gages are fixed gages similar to that illustrated in Figure 30-6-2.

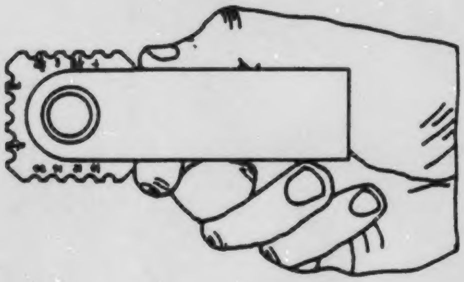


Figure 30-6-2. One type of wet film gage (courtesy of Nordson Corp. Amherst, Ohio)

All wet film gages operate on the same principle. Wet film gages use either comb-like teeth, an eccentric wheel, or a calibrated spherical section. The comb type illustrated in Figure 30-6-2 has two outer legs of equal length and progressively shorter inner legs. The gage is pressed into the wet film in a position perpendicular to the surface and then removed. Wet film thickness is indicated by the shortest leg which has paint on its tip. Wet film readings must be taken immediately after application of the coating.

The relationship of wet film thickness to dry film thickness is directly proportional to the percent solids by volume in the paint. Evaporation of the volatile materials reduces the film thickness upon drying. The relationship is theoretically expressed by the following formula:

$$T_d = T_w \times \frac{V}{100} = \frac{1600G}{A} \times \frac{V}{100} = \frac{16GV}{A} \qquad \text{Formula 30-6-2}$$

where:

T_d = dry film thickness in mils

T_w = wet film thickness in mils
V = percent solids by volume
G = volume of paint used in gallons
A = area in ft^2 covered by paint used

Example

Given

A 10ft x 10ft flat surface is covered with ½ gallon of paint having 50% solids by volume.

Problem

What are the theoretical wet and dry film thicknesses?

Solution

$$T_w = \frac{1600G}{A}$$

$$= \frac{1600 \times .5}{100}$$

$$= 8 \text{ mils}$$

$$T_d = T_w \times \frac{V}{100} \quad \text{or} \quad T_d = \frac{16GV}{A}$$

$$= 8 \times \frac{50}{100} \qquad = \frac{16 \times .5 \times 50}{100}$$

$$= 4 \text{ mils} \qquad = 4 \text{ mils}$$

Wet film thickness gages are used as a guide during coating application. If proper wet film thickness is obtained, there is better assurance of meeting dry film thickness requirements. The project specification may also require calculation of wet film thickness by the quantity method. In either case, the theoretical relationship of wet film thickness to dry film thickness is affected by local circumstances including variation in substrate surface texture (anchor pattern), operator skills and waste, environmental effects, and application techniques. It is normally possible to develop a correction factor for local conditions. For example, if actual dry film thickness is typically 80% of theoretical dry film thickness, the correction factor of .8 is used in further calculations of dry film thickness.

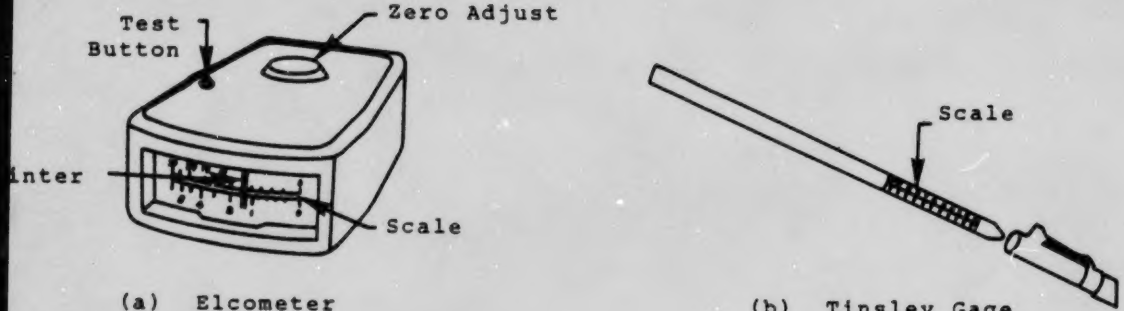
Dry Film Thickness Inspection

Inspection of dry film thickness should be nondestructive in nature. Typically, this is done by Eddy Current testing. Inspection by destructive methods, such as depth pins and scrapings, are used only when allowed by the project specification. Today's state-of-the-art provides nondestructive test instruments for magnetic substrates but not for nonmagnetic substrates. For non-magnetic substrates, such as concrete, dry film thickness is typically calculated from wet film thickness measurements although the project specification may permit use of scratch gages or other destructive tests.

There are several kinds of dry film thickness gages on the market for use with magnetic substrates. Simplified sketches of four gages are illustrated in Figure 30-6-3.

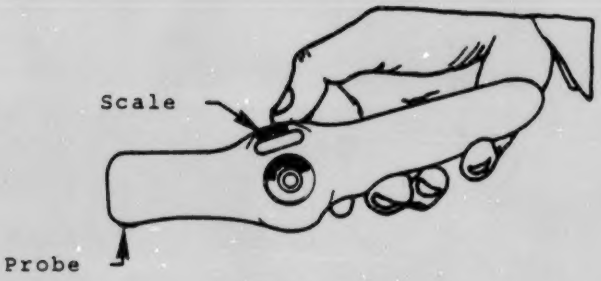
All of the gages illustrated in Figure 30-6-3 work on a magnetic principle. The instrument's response to the magnetism of the substrate is directly affected by the thickness of the coating. The gage is designed to convert this affect to a direct readout of coating thickness. The Elcometer, when placed on the dry film, gives a readout when the test button is depressed. The Tinsley gage uses a small magnetic and a precision spring. Dry film thickness is indicated by how far the magnet pulls the spring. The Microtest and Accuderm measure the magnetic effect between the probe and the substrate and readout in dry film thickness.

The specific gage used has errors. These errors stem from gage inaccuracies, affect of the anchor pattern variations, and magnetic solids in the coating material.

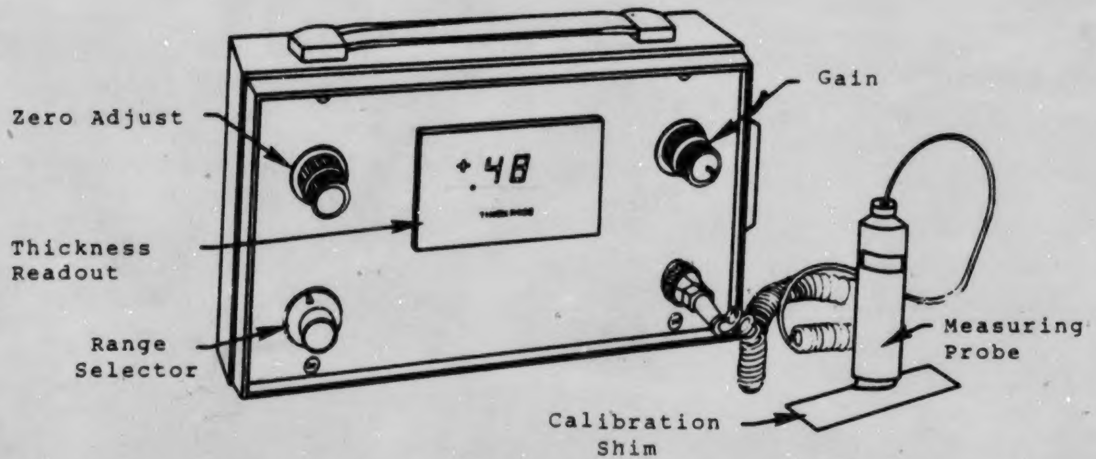

Test Button
Zero Adjust
inter
Scale
Scale

(a) Elcometer

(b) Tinsley Gage


Scale
Probe

(c) Tooke Microtest


Zero Adjust
Gain
+.48
Thickness Readout
Range Selector
Measuring Probe
Calibration Shim

(d) Unit Process Assemblies "Accuderm"

Figure 30-6-3. Simplified Illustrations of Dry Film Thickness Gages.

Calibration shims are used to calibrate the gage. Nonmagnetic shims of known thickness are placed on the prepared substrate and read with the gage. Either the gage is adjusted or correction factors are developed to improve accuracy of measurements. In the event a dispute arrises between the owner and applicator on actual dry film thickness, resolution is typically obtained by scraping a small piece of the coating system with a razor down to bare metal and measuring dry film thickness with a depth micrometer.

Holiday Inspection

The project specification may require inspection for holidays by use of special gages. One type of holiday detector uses a high voltage on the order of 8,000 to 15,000 volts and is known as spark testers. As the brush or coil probe passes over the coating, a spark occurs where holidays exist. A more commonly used gage is essentially nondestructive in nature. It employs a low voltage of 75 volts or less and an electrically conductive liquid. The probe is encased in a celulose sponge which is saturated with the liquid. When a holiday is encountered, an electric current flows through the liquid to the substrate metal. Simplified sketches of these nondestructive detectors are illustrated in Figure 30-6-4.

Inspection of Film Appearance

In conjunction with film thichness inspections, visual inspections of film appearance are performed by the inspection agency. These inspections determine if defects exist such as runs, sags, blisters, and skips. Visual inspection may employ workmanship samples which consist of coated panels having least acceptable conditions.

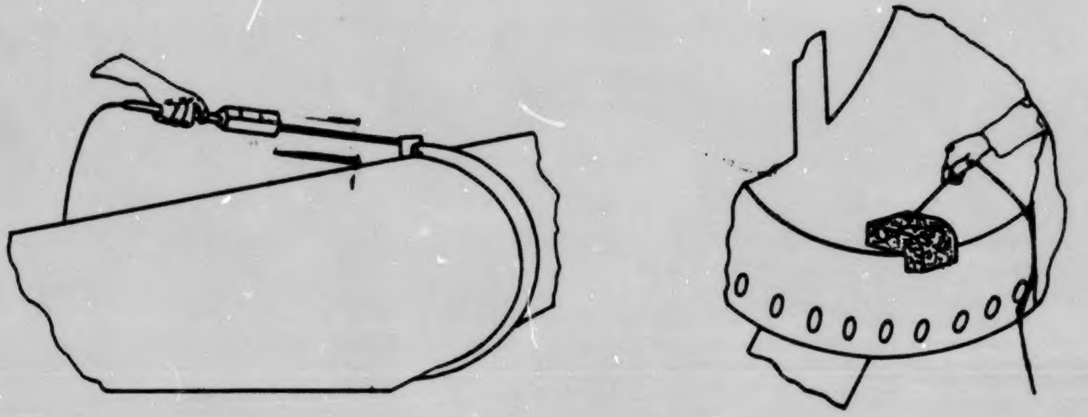


Figure 30-6-4. Simplified Sketches of Holiday Detectors

FINAL ACCEPTANCE CRITERIA

Source of Criteria

The project specification or a supplementary quality assurance document specifies the criteria upon which final acceptance of the coating system is based. The results of visual and gage inspections are compared with the criteria by the inspection agency and the coating system is either accepted or rejected. Final acceptance reports or nonconformance reports document these decisions.

Typical Criteria

Final acceptance criteria typically includes the following:

- film thickness - Dry film thickness is within specified limits.
- runs - Major runs or sags are not acceptable. They must be removed to bare substrate or to a previously accepted coat and recoated.
- skips - Skips and damaged areas are not acceptable. They must be removed to bare substrate or previously accepted coat and recoated.
- pinholes - Pinholes are permitted as specified by the project specification. The specification may stipulate "pinhole free" or describe an acceptable number of pinholes. Typically, no more than two pinholes are permitted in an area defined by a six inch radius as measured from any given pinhole. Any one of the conditions for pinholes listed in Table 30-6-6 may be stipulated by the project specification.

Table 30-6-6
TOTAL NUMBER OF ALLOWABLE PINHOLES

Surface Area Being Coated (square feet)	Cond. "A" Pinhole Free	Cond. "B" Relatively Pinhole Free	Cond. "C" Commercially Continuous
10	0	1	5
10 - 50	0	2	10
50 - 100	0	5	20
100 - 500	0	10	30
500 - 1000	0	15	50
1000 - 5000	0	25	75

GLOSSARY

- Abrasion - wearing away of material in small shreds as a result of friction.
- Abrasive - a substance, such as sand, grit, steel shot, etc. used in blast or abrasive cleaning.
- Acid etch - a process for producing surface profile through dissolution of a surface layer by contact with dilute acid.
- Adhesion - the bond or attraction of a coat of paint to the underlying material, such as a substrate or another coat.
- Anchor Pattern Profile - roughness of a blast-cleaned surface measured by the height from the bottom of a valley to the top of the highest adjacent peak. It depends largely on the original condition of the surface and the abrasive used and should vary for different paint systems.
- Batch - that quantity of material produced in one operation.
- Batch sample - a small retained quantity of material representative of a specific production run.
- Blast cleaning, blasting - the use of abrasives propelled through nozzles or by centrifugal wheels to prepare a surface for coating.
- Blistering - the formation of bubbles in a cured, or nearly cured, coating (paint) film.
- Certification - confirmation by a document under hand or seal as being true or as meeting a standard or as being as represented.
- Chalking - that phenomenon manifested in paint films by the presence of loose, removable powder, evolved from the film itself, at or just beneath the surface. Chalking may be easily detected by rubbing the film with a cloth of contrasting color or with the finger-

tip (ASTM D-659-44).

- Checking - a defect in the paint or varnish coating that manifests itself by slight breaks in the surface of the film.
- Coating applicator - one who applies a protective or decorative coating.
- Coatings (paints) - polymeric materials applied in a fluid phase which cure or dry to continuous films.
- Coating system - a multicomponent polymeric protective film usually consisting of prime, intermediate, and finish coats.
- Coating work - an all-inclusive term to define all operations required to accomplish a complete coating job. The term shall be construed to include materials, equipment, labor, preparation of all surfaces, control of ambient conditions, application of coating systems, inspection, etc.
- Coating-work map - an outline drawing for all areas to be coated, with sufficient detail and identification to clearly define each area. This map shall normally be prepared by the owner or the coating inspection agency.
- Compatible - suitable to be combined with other substances or to adhere properly to other parts of a system; capable of resisting the chemical, physical, and other effects of the intended service condition.
- Concrete-curing agents - materials applied to a concrete surface to maintain proper moisture conditions for curing.
- Contaminant - a foreign substance, inadvertently added to a coating or found on the substrate, that adversely affects the application, adhesion, curing, and/or subsequent performance of the applied coating.

Atmospheric moisture and condensation are considered to be substrate contaminants.

- Contamination - lack of cleanliness of substrate; adulteration of coating product.
- Controlled-access area - in a nuclear facility, a defined area access to which is controlled for the purpose of protecting individuals from exposure to radiation and radioactive materials.
- curing - the changing of the physical properties of a coating by chemical reaction accomplished by the action of heat and/or an activator.
- Decontaminate - to remove radioactive nuclides (the contaminant) from a surface.
- Design-basis accident (DBA) - a hypothesized accident the characteristics and consequences of which are utilized in the design of those systems and components pertinent to the preservation of radioactive material barriers and the restriction of radioactive material release from the barriers. The potential radiation exposures resulting from a design-basis accident are greater than from any similar accident postulated from the same general accident assumptions. For example, the consequences of a complete severance of a recirculation loop line are more severe than those resulting from any other single pipeline failure.
- Deviation - completed work that is not in accordance with the specification requirements.
- Delamination - separation of one coat or layer from another coat or layer.
- Documentation - The assembling or dissemination of written information or records in substantiation of work done or facts quoted.
- Dry-film thickness (DFT) - depth of applied coating when dry, expressed in mils.

- Flaking (Scaling) - the detachment of small pieces of the coating film. This is usually preceded by cracking, checking, or blistering.
- Form-release agent - the oil or plastic coating used on concrete forms to reduce damage to the concrete and to the forms when they are stripped from the hardened concrete.
- Holiday - a pinhole, skip, discontinuity, or void in coating film.
- Holiday detector - a device for the detection of pinholes or holidays.
- Inspection - examination to determine conformance to specifications.
- Inspection agency - a person or persons empowered to act for the owner to verify conformance of the coating work with documented specifications, instructions, and procedures. The inspection agency may be part of the owner's or his representative's organization, may be a representative of the coating manufacturer or the coating applicator or may be an independent organization, provided the inspection personnel do not report directly to the immediate supervisor responsible for the coating work.
- Interface - the boundary between coats, phases, or systems.
- Laitance - a fine, whitish accumulation on concrete surfaces. It consists mainly of cement particles that were carried by water rising to the surface of freshly placed concrete. The resulting concrete surface is unsuitable for proper adhesion or bond of subsequent fillers or protective coatings.
- Magnetic gauge - an instrument that will nondestructively measure the thickness of a nonmagnetic coating over a ferrous substrate.

- Masonry - a built-up construction consisting of building units made of clay, shale, concrete, stone, etc., set in mortar.
- Mil - one one-thousandth of an inch (0.0254 millimeters)
- Pickling - a surface treatment for steel to remove rust and mill scale by immersion in an acid solution which may contain an inhibitor.
- Pot life - the time interval at a specified temperature, after the components of chemically cured coatings have been combined and mixed, during which the mixed material displays normal application and film-forming properties.
- Primer - the first complete coat of a coating system applied to a surface. The type of primer varies with the surface, its condition, the intended purpose, and the coating system to be used.
- Profile - a surface roughness resulting from abrasive blasting, chemical etching, or other cause. It is a measure of the anchor pattern.
- Profile depth - the distance measured perpendicular to the surface between adjacent high and low points of a profile.
- Project specification - a written document designed to ensure execution of the coating work for a project in accordance with the owner's requirements. It is usually comprised of general, legal, and technical specifications governing the work, together with related pricing requirements.
- Protective coating - an adherent polymeric film applied to a substrate for protection from environmental attack and for esthetic effect.
- Runs - the flow of an excessively applied coating which results in an elongated pattern of irregular coating films over a small vertical or sloped surface

area such as a point or an angle.

- Sags - the flow of an excessively applied coating which results in a broad pattern of irregular coating films over a large vertical or sloped surface area.
- Scratch gage - an instrument that makes a cross-sectional scratch through a coating and optically measures its thickness. It may be used on any nonbrittle coating over any substrate.
- Shelf life - the period of time, as stated by the coating manufacturer, during which a coating does not become unusable.
- Spatter - deposit on or adjacent to weld seams produced by weld metal during electric hand welding operation. It is inacessible for painting, and the sharp forms do not lend themselves to being coated; therefore it must be removed prior to painting.
- Substrate - the uncoated base surface to which a coating is to be applied.
- Surface defects - the existence in a coating of any of the following conditions which impair its performance for the intended service: (a) fine-line cracking, (b) checking, (c) alligatoring, (d) mud-cracking, (e) embrittlement, etc.
- Surfacer - a material used to fill and smooth a surface.
- Wet-film thickness (WFT) - the depth, expressed in mils, of an applied coating measured immediately after application.
- Work - all or any part of such labor (including the services of all trades), methods, materials, equipment, and transportation or other facilities as may be necessary to complete the contract.

EXERCISES

The following exercises serve to review the material presented in this module. An answer key is also provided following each section.

A. The following exercises concern the Fundamentals of Protective Coatings.

1. Name two purposes of protective coatings.
    a.
    b.

2. Define these terms:
    a. Substrate

    b. Wet film thickness

    c. Dry film thickness

    d. Mil

3. What is the purpose of qualifying coating materials?

4. Describe the relationship of coating material qualification tests with Design Basis Accident.

5. Describe the condition of a Near-White Blast Cleaned Surface Finish.

6. Describe the condition of a Commercial Blast Cleaned Surface Finish.

Check your answers for these exercises on the Fundamentals against the following answer key:

1. a. To protect surfaces from corrosion
   b. To provide a surface which can be decontaminated

2. a. Substrate is the uncoated base surface to which a coating is to be applied-
   b. Wet film thickness is the depth in mils of an applied coating measured immediately after application.
   c. Dry film thickness is the depth in mils of applied coating when dry.
   d. Mil is one-one thousandth of an inch (0.001").

3. To determine that the coating material will resist deterioration when subjected to the environment of a Design Basis Accident.

4. The qualification tests simulate the environment of a DBA including steam-air atmospheres, elevated temperatures, ionizing radiation, and immersion or spray with and without chemicals.

5. Near-white blast cleaned surface finish has at least 95% of any given area free of all foreign material with the remaining area having only slight discoloration.

6. Commercial blast cleaned surface finish has at least 2/3 of the surface area free from all foreign material with the remaining area having only light discoloration, slight staining, or light residues.

B. The following exercises concern the Elements of Quality Assurance for Protective Coatings by circling the letter of the best choice for the following questions and statements. An answer key is provided following this set of exercises:

1. The primary objective of the coating material supplier's quality assurance program is to:
    a. qualify applicators of coating systems.
    b. control formulation and processing.
    c. inspect wet film thickness.
    d. document application techniques.

2. Coating material product identification is primarily provided by:
    a. receipt inspection
    b. supplier's certification
    c. deviation reports
    d. inspection reports

3. The minimum information provided by labeling of protective coating containers is:
    a. product designations, and shelf life.
    b. product designation, percent solids and certification number.
    c. product designation, batch number, and date of manufacture.
    d. product designation, percent solids and batch number.

4. Sample retention by the coating material supplier is to provide samples for:
    a. shelf life testing
    b. prequalification testing

c. coating test panels
d. additional testing to resolve disputes

5. The purpose of surface preparation of substrates is to provide:
   a. adequate adhesion of the coating system.
   b. cleanliness conditions suitable for inspection
   c. bright polished and smooth surfaces
   d. DBA environmental conditions.

6. Environmental conditions which may adversely affect the substrate are (circle all correct responses)
   a. temperature
   b. humidity
   c. chemical vapors
   d. vibration

7. Contaminants are removed from substrate surfaces because contaminants may:
   a. interfere with coating application.
   b. cause lack of adhesion.
   c. interfere with curing.
   d. all of the above.

8. The term "coating system" means:
   a. the method of application of coating.
   b. the substrate to be coated.
   c. the protective film usually comprized of primer, intermediate and finish coats.
   d. the composite procedures for surface preparation, coating application and inspection.

9. The purpose of daily inspection reports is to:
   a. record dry film thickness.
   b. report deviations.
   c. describe practices employed by the applicator.
   d. accept coating systems.

10. The deviation report serves to:
   a. record wet film thickness.
   b. accept coating systems.
   c. obtain correction of conditions which fail to meet specified requirements.
   d. describe the inspection program for coating applications.

11. The acceptance inspection report serves to:
   a. accept coating systems.
   b. report deviations.
   c. describe daily conditions.
   d. document removal of contaminants.

Check your answers on the exercises covering the Elements of Quality Assurance for Protective Coatings against the following answer key.

1. b
2. b
3. c
4. d
5. a
6. a, b, c
7. d
8. c
9. c
10. c
11. a

C. The following exercises cover the information on Coating Inspection Techniques. An answer key is provided following this set of exercises.

1. Define:
    a. run

    b. sag

    c. holiday

2. Why are set film measurements made? (State two reasons)

3. What type of inspection is used for thinning of coating materials and what is its primary objective?

4. Describe how to make wet film thickness measurements using the quantity method.

5. Describe the principle of operation of dry film thickness gages.

6. Why are dry film thickness gages not used on common concrete substrates?

7. Calculate dry film thickness given:
percent solids - 40%
volume of paint - 3 gallons
area covered - 600 ft^2

8. Describe the use of calibration shims.

9. Describe the operation of nondestructive holiday detectors.

10. Describe the measurement of wet film thickness with a comb type wet film gage.

Check your answers to the exercises on Coating Inspection Techniques against the following answer key:

1. a. run is the flow of excessively applied coating which results in an elongated pattern of irregular coating films over a small vertical or sloped area.
   b. sag is the flow of excessively applied coating which results in a broad pattern of irregular coating films over a large vertical or sloped area.
   c. holiday is a skip, pinhole, discontinuity, or void in coating film.

2. a. to serve as a guide during application to determine that correct film thickness is being applied.
   b. to permit calculation of dry film thickness.

3. Visual inspection having the objective of ensuring compliance with requirements for thinning material type and quantity.

4. The volume of paint used in gallons and the area covered in square feet by that volume are measured. Using the formula $T_W = \frac{1600G}{A}$, wet film thickness is calculated.

5. Dry film thickness gages are sensitive to magnetic materials. The degree of interference by the nonmagnetic dry film is converted by the gage to dry film thickness.

6. Common concrete substrates are nonmagnetic and therefore do not produce a reading on the gage.

7. 3.2 mils
   $(T_d = \frac{16GV}{A} = \frac{16 \times 3 \times 40}{600} = 3.2)$

8. Calibration shims are nonmagnetic and of known thickness. Reading the shims placed on the substrate indicate accuracy of gage.

9. A low voltage is applied between the detector probe and the substrate. Electrically conductive fluid is pushed by the probe along the coating film. Holidays in the film permit current flow through the fluid which indicates their presence.

10. Immediately after application of coating material, the wet film gage is pressed at right angles into the film and withdrawn. Evidence of paint on the shortest leg indicates wet film thickness.

D. Film Thickness Calculations and Inspection

  1. Using the Procedures given in this module, calculate wet or dry film thickness as outlined in the procedure.

  2. Inspect dry film thickness of a coating system as outlined in the Procedures.

MATERIALS

The following materials are required to support this module:

1. Wet film thickness gage (any type)
2. Dry film thickness gage (any kind)
3. Calibration shims compatible with the dry film thickness gage
4. Copy of coating applicator's procedures (optional)
5. Copy of coating project specification (optional)

PROCEDURES

1. As requested in Exercise 1 of Part D of the Exercises section, calculate wet or dry film thickness as indicated for the following given conditions:
    a. Eight gallons of primer having 60% solids by volume are used to coat 4800 square feet. Known application efficiency is 80%.
    dry film thickness =
    b. A finish coat is applied with paint having 40% solids by volume in a manner which gives a wet film thickness of 5 mils.
    theoretical dry film thickness =

2. As requested in Exercise 2 of Part D of the Exercises section, inspect dry film thickness of a coating system identified by the instructor using available gages. Complete data table 30-6-7 to document the inspection.

DATA TABLE

Table 30-6-7
DRY FILM THICKNESS DATA TABLE

Name of gage used: ______________________

Calibration data:

Shim	Gage Reading
______	______
______	______
______	______

System inspected: ______________________

Dry film thickness: ______________________

3. Visually inspect a coating system identified by the instructor. Complete data table 30-6-8.

Table 30-6-8
Visual Inspection Data Table

System inspected ______________________

Defects:	Present	Not Present	Location
Sags	______	______	______
Runs	______	______	______
Blisters	______	______	______
Holidays	______	______	______

REFERENCE MATERIALS

ANSI, N101.4, Quality Assurance for Protective Coatings Applied to Nuclear Facilities, American Institute of Chemical Engineers, 1972

ANSI, N101.2, Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities, American Institute of Chemical Engineers, 1972

ANSI N5.9, Protective Coatings (Paints) for the Nuclear Industry, American Institute of Chemical Engineers, 1967

NACE, Coatings and Linings Handbook, National Association of Corrosion Engineers, 1978

NACE, Surface Preparation Handbook, National Association of Corrosion Engineers, 1977

NACE, Industrial Maintenance Painting, National Association of Corrosion Engineers, 1978

Clive H. Hare, A Layman's Guide to Surface Coatings and Their Application, Cadillac Paint and Varnish Company, Inc., undated

NACE, Basic Corrosion Course, National Association of Corrosion Engineers, 1977

Thomas A. Cross, Corrosion Control Coatings, Plant Engineering, Technical Publishing Company, December, 1978

USNRC, Regulatory Guide - Quality Assurance Requirements for Protective Coatings Applied to Water-Cooled Nuclear Power Plants, U.S. Nuclear Regulatory Commission, 1973

TEST

A. Answer the following questions as either true or false.

____ 1. Protective coatings (paints) serve three primary purposes with respect to reactor containment facilities. These purposes are:

- a. to protect surfaces from corrosion,
- b. to provide a vapor barrier for the reactor building walls, and
- c. to provide an additional shielding layer to provide biological protection from the Nitrogen-16 gamma radiation present in the containment building.

____ 2. The surface to be coated is the substrate and the films applied comprise the coating system.

____ 3. Defects in coating systems typically consist of runs, sags, and holidays. Failure to meet dry film thickness requirements is also a deviation.

____ 4. The cleaning process to prepare the substrate prior to coating may be adversely affected by such things as temperature, humidity, radioactive effluents, smoke, and excessive sunlight.

____ 5. Protective coatings protect the substrate from corrosion and offer a surface which can be decontaminated.

____ 6. Coating materials are qualified under conditions which simulate the environment of the Cold Water Accident. Once qualified, the supplier's quality assurance program must control formulation and processing such that material performance is unaffected or requalification occurs.

____ 7. The contamination-decontamination tests provide quantitative evaluation of the ease and degree of contamination and decontamination of protective coatings.

____ 8. The dynamic elevated temperature-pressure test determines performance of the coating system under the moisture-temperature-pressure-chemical environment anticipated during caustic corrosion of the reactor coolant system within the containment building.

____ 9. The irradiation test determines the performance of the coating system when subjected to a radiation dose anticipated during a Design Basis Accident.

____ 10. Near-White and Commercial blast cleaned surface finishes are the two most common preparations of steel substrates. The major differences in these finishes is the percentage of area to be clean to bare metal and the extent of foreign matter on the remaining area.

____ 11. Product identity of coating materials is provided by the material supplier's certification of each batch.

____ 12. Each container of coating materials is labeled to identify product designation, specific gravity, and latent heat of vaporization.

____ 13. Samples of each batch of coating materials are retained by the manufacturer for two years or the shelf-life whichever is shorter. These samples permit additional testing if necessary to resolve disputes on the quality of the materials.

____ 14. The owner may require the applicator to conduct performance verification tests of the coating materials to be used. These tests are typically the Eddy Current Test, the Charpy V-Notch Test and the Bend Test.

____ 15. Surface preparation of substrates is extremely important in that the crystalline structure must shift from a face-centered-cubic mode to a body-centered-cubic mode.

____ 16. Control and removal of contaminants is necessary during preparation of substrate surfaces. This includes control or removal of blasting abrasives, grit, and dust; welding fumes and subsequent contaminants; welding scale and spatter, pickling residues; cement spatter, laitance, and mortar; incompatible form release agents and curing compounds; and any other deleterious matter.

____ 17. The environmental conditions of temperature, humidity and vapors are virtually unimportant when the application of coatings is considered. This is because of the tremendous adhesive nature of these coatings.

____ 18. The applicator uses written procedures for controlling coating work. These procedures describe the practices used for qualification of applicators; receiving, storage, handling, and dispensing of coating materials; application equipment; application parameters such as environmental conditions, regulation of equipment, ventilation, cleanliness, viscosity, viscosity control, film thickness control, number of coats, and curing time; preparation of coating materials such as mixing, thinning, and activating; health, safety, and fire protection requirements; instruments and their use for measuring relative humidity, temperature, viscosity, wet and dry film thicknesses, and holidays; and the documentation to be provided.

____ 19. The inspection agency issues daily inspection reports, acceptance inspection reports, and as necessary, deviation reports.

____ 20. Dry film thickness measurements serve as a guide to the applicator and permit calculation of wet film thickness.

____ 21. Dry film thickness gages work on a magnetic principle and are used for film thickness measurements of magnetic substrates. Nonmagnetic shims of known thickness are used to calibrate these gages.

____ 22. Inspections are comprized of record reviews, visual inspection, and special gage inspections. Inspection elements include coating materials, storage, equipment, safety, substrates, environment, thinning, application, film thickness, and film appearance. Can you state the primary objective of inspection of each of these elements?

____ 23. Holiday detectors may be destructive (spark types) or nondestructive (low voltage-electrolyte types). Those normally permitted are nondestructive which detect holidays by the passing of a current flow through the conductive fluid at locations of holidays.

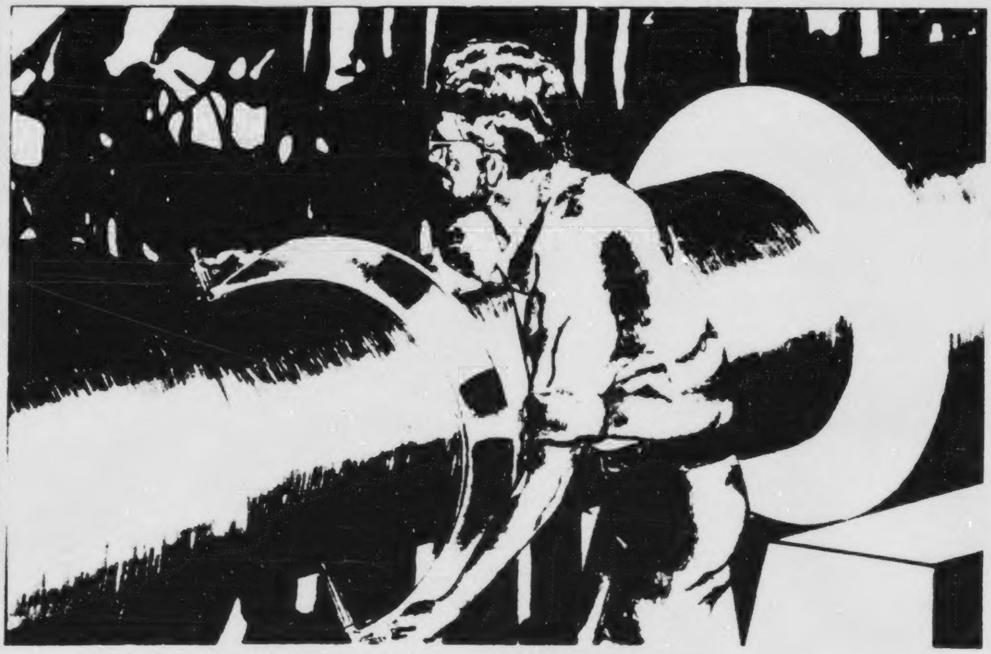
____ 24. A controlled-access-area in a nuclear facility is an area to which access is controlled for the expressed purpose of protecting individuals from inhaling toxic airborne fumes from protective coatings.

____ 25. A coating-work map is supplied to each person applying protective coatings so that they don't get lost in the plant.

NUCLEAR TECHNOLOGY

MODULE 30-7

PRESSURE VESSEL INSPECTION



COURSE 30 MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

4800 LAKEWOOD DRIVE, WACO, TEXAS

COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

MODULE 30-1	Pump Inspection
MODULE 30-2	Pump Functional Testing
MODULE 30-3	Valve Inspection
MODULE 30-4	Piping Inspection
MODULE 30-5	Sufrace Cleaning Inspection
MODULE 30-6	Protective Coating Inspection
MODULE 30-7	Pressure Vessel Inspection
MODULE 30-8	Rotating Equipment Inspection

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INTRODUCTION

The reactor pressure vessel can be considered the heart of the reactor coolant system for a nuclear power plant.

The heat generated by the fission process in the nuclear fuel is utilized to create steam to drive the turbine-generator. Because of the high pressures and temperatures to which the reactor pressure vessel is subjected, great care must be exercised in its design and fabrication. Heat-up and cooldown effects during plant startup and shutdown cause great stresses on the reactor pressure vessel. The reactor operator must follow operating procedures closely to ensure that the design limitations on this pressure vessel are never exceeded.

This module is devoted to the design and fabrication of the reactor pressure vessel. Although there are other smaller pressure vessels, in various systems in a nuclear generating station, the one vessel of major concern insofar as the resultant consequences of its possible failure is the reactor pressure vessel or simply reactor vessel.

The potential catastrophic failure of the reactor vessel has necessitated rigid standards for its design, fabrication, testing and quality control. Destructive testing is employed to establish the material properties and limits which the fabrication material can withstand. In this manner, it is determined if the material can satisfactorily withstand the stresses and rigors imposed upon an operating reactor vessel. Nondestructive testing is employed to determine the existence and location of flaws in the vessel material and in the welds that join different sections of the vessel together. By thus limiting the number and size of flaws or discontinuities, one can reduce the probability of vessel catastrophic failure.

For purposes of illustration in this module, a pressurized water reactor (PWR) vessel is considered. However, it should be realized that the fabrication and testing requirements for a boiling water reactor (BWR) vessel are somewhat less restrictive than those for a PWR due to its lower operating pressure and temperature. However, the design, fabrication and testing requirements for both PWR and BWR vessels are very similar.

MODULE PREREQUISITES

The prerequisites for this module are:

1. Prior study or experience in basic metallurgy and metals properties (Example: Nuclear Technology Course #15, Metallurgy and Metals Properties).
2. Prior study or experience in nondestructive examinations (Example: Nuclear Technology Course #26, NDE Techniques I).

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. State the primary reason for application of stringent requirements to the design, fabrication, installation, and operation of reactor vessels.
2. Recognize sources of stresses on the reactor vessel in operation and correlate the significance of these sources with ¼ and 3/4 thickness locations.
3. Define elasticity and brittle fracture.

4. Define T_{NDT} and RT_{NDT}.
5. Describe how T_{NDT} and RT_{NDT} are determined.
6. State the purpose of chemistry analysis and tensile tests of materials.
7. Describe the effects of neutron irradiation of the reactor vessel on RT_{NDT}.
8. Describe the basis for the establishment of heatup and cooldown limits for reactor operation.
9. Name the documents used for procurement of reactor vessels.
10. State the purpose of volumetric nondestructive examination of materials used for fabrication of reactor vessels.
11. Briefly describe controls applicable to weld repair of flaws in materials.
12. Describe certification of material by the material manufacturer.
13. Describe marking of materials.
14. State three purposes of fabrication processing.
15. Describe typical fabrication controls by indicating the nature of controls applied to (a) material identity, (b) dimensions, (c) welding, and (d) nondestructive testing.
16. State the purpose of reactor vessel hydrostatic testing and briefly describe conduct of hydrostatic testing.
17. Describe the reactor vessel certification by the fabricator.
18. State rationale for source inspection of reactor vessels by the nuclear utility.

NOTES TO INSTRUCTOR/STUDENT

Due to the very specific nature of this module and because of the detailed code requirements discussed, it would be very useful for the student/trainee to have access to Section III, Subsections NA and NB, of the ASME Boiler and Pressure Vessel Code for additional reference. A brief review of metallurgy and metals properties and nondestructive examination would also be beneficial for a more complete understanding of reactor pressure vessel construction and inspection.

SUBJECT MATTER

FUNDAMENTAL CONCEPTS

Need for Mechanical Inspection of Pressure Vessels

The most serious accident which could occur at a nuclear generating station is the catastrophic failure of the reactor vessel. Such failure makes cooling of the reactor fuel extremely difficult because a level of water probably could not be sustained in the reactor vessel. Therefore, stringent standards of testing and quality control are applied to the design, fabrication, and installation of reactor vessels.

Reactor Vessel Functions

The reactor vessel is a highly complex pressure vessel which has a number of functions in operation of a nuclear power plant. Of the two basic types, pressurized water reactors (PWR) and boiling water reactors (BWR), the reactor vessel serves essentially the same functions. These are:

- serve as pressure retaining vessel
- provide physical support to the reactor core
- receive inlet and outlet cooling water for PWRs and recirculating water for BWRs
- for BWRs, receive feed water and discharge steam
- provide physical support for control rod mechanisms
- provide access to reactor core for refueling
- receive instrumentation sensing lines and detectors.

A typical reactor vessel for a PWR is illustrated in Figure 30-7-1. Examination of Figure 30-7-1 reveals several important concepts. Stresses are not uniformly distributed and material thicknesses vary in order to provide sufficient strength based on stresses seen in operation. Internal surfaces are clad with corrosion resistant material. Location and orientation of nozzles and penetrations

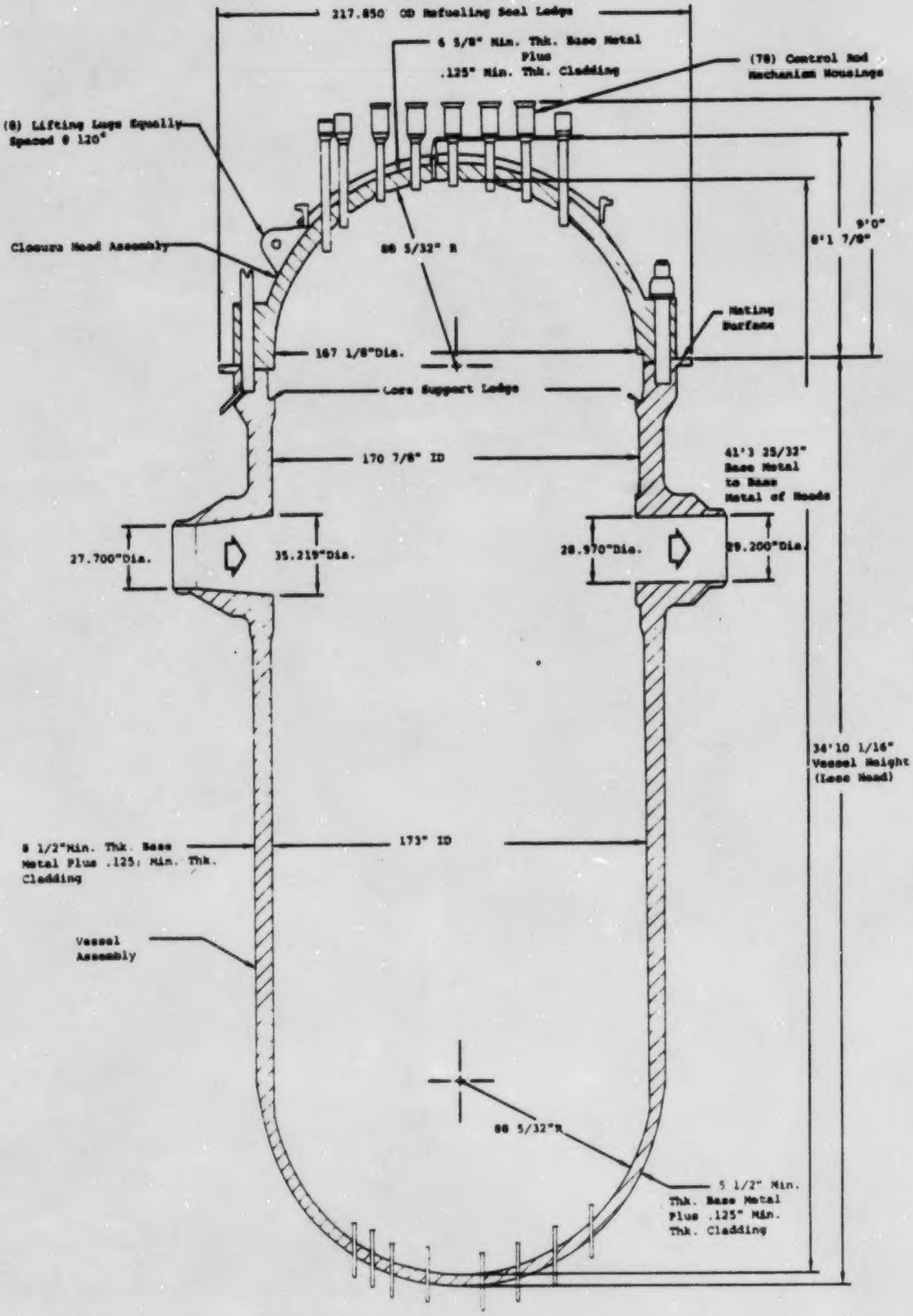
217.850 OD Refueling Seal Ledge
6 5/8" Min. Thk. Base Metal Plus .125" Min. Thk. Cladding
(78) Control Rod Mechanism Housings
(8) Lifting Lugs Equally Spaced @ 120°
Closure Head Assembly
88 5/32" R
9'0"
8'1 7/8"
Mating Surface
167 1/8"Dia.
Core Support Ledge
170 7/8" ID
41'3 25/32" Base Metal to Base Metal of Heads
27.700"Dia.
35.219"Dia.
28.970"Dia.
29.200"Dia.
34'10 1/16" Vessel Height (Less Head)
8 1/2"Min. Thk. Base Metal Plus .125: Min. Thk. Cladding
173" ID
Vessel Assembly
88 5/32"R
5 1/2" Min. Thk. Base Metal Plus .125" Min. Thk. Cladding

Figure 30-7-1. Typical Reactor Vessel for a PWR

must be compatible with connecting piping and tubing. A bolted closure head assembly provides for access for refueling. Large dimensions are involved. The reactor vessel receives a relatively large neutron and gamma radiation flux during power operation. Thermally induced stresses are important due to the relatively large material thicknesses. Except for the closure head bolting, an all welded construction is used. Material and weld joint strength and ductility are important in order to avoid failure. Soundness of materials and welds is important in order to avoid failure.

Stresses Developed in the Reactor Vessel Wall

Stresses arising from coolant system pressure exerted against the vessel wall are always tensile in nature. Stresses arising from temperature gradients across the vessel wall can either be tensile or compressive. The type of stress is a function of the wall thickness and reverses from heatup to cooldown. During system heatup, the vessel outer wall temperature lags the inner wall temperature. The stresses produced by this temperature gradient and by system pressure produce the profile of Figure 30-7-2.

It can be seen that while the pressure stresses are always tensile, at the 1/4 thickness (1/4T), the temperature stresses are compressive. Thus the stresses at the 1/4 T location tend to cancel during system heatup. At the 3/4 T location, however, the stresses from both temperature and pressure are tensile and thus reinforce each other during system heatup. For this reason the 3/4 T location is limiting during system heatup.

During system cooldown, the stress profile of Figure 30-7-3 is obtained. During cooldown, the temperature of the outer wall lags the temperature of the inner wall and is at a higher temperature. It can be seen that during

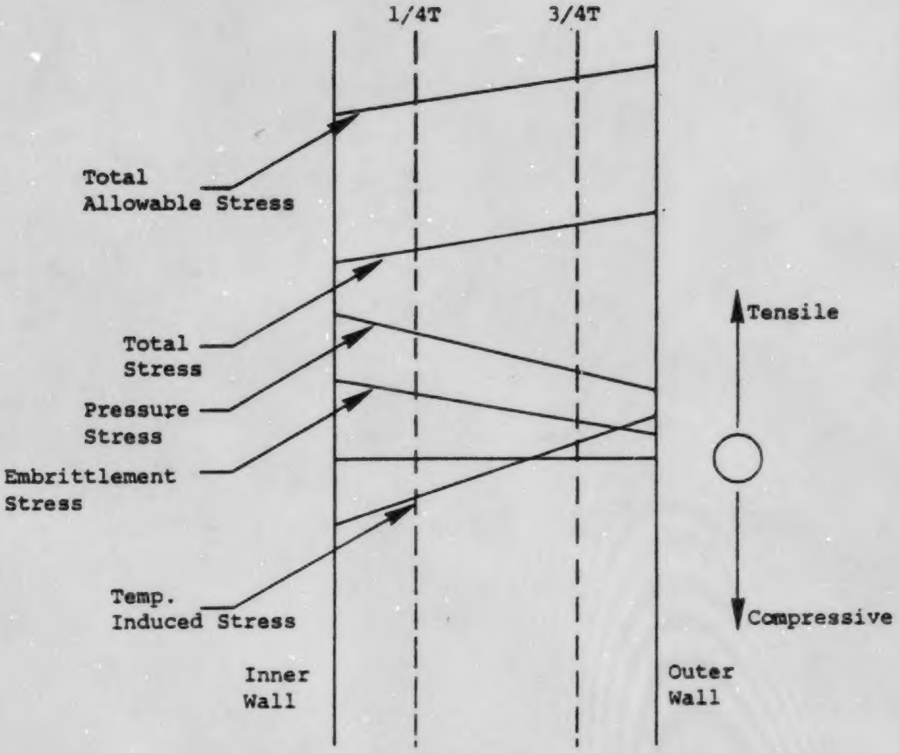
1/4T
3/4T
Total
Allowable Stress
Total
Stress
Pressure
Stress
Embrittlement
Stress
Temp.
Induced Stress
Tensile
Compressive
Inner
Wall
Outer
Wall

Figure 30-7-2. Heatup Stress Profile

cooldown, the stresses at the 3/4 T location are tensile due to system pressure and compressive due to the temperature gradient. Thus during cooldown, the stresses at the 3/4T location tend to cancel as shown in Figure 30-7-3. At the 1/4 T location, however, the pressure and temperature stresses are both tensile and thereby reinforce each other. Thus the 1/4 T location is limiting during system cooldown.

Neutron irradiation of the vessel wall produces damage that makes it more brittle. For this reason, an embrittle-

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ment stress component must be included in the stress profile of the vessel wall. The time integrated neutron dose (fluence) is greater at the 1/4 T location than at the 3/4 T location, as shown in Figure 30-7-4. For this reason, the total stress realized during system cooldown more closely approaches the total allowable stress. Because system cooldown is a more limiting situation, the 1/4 T value is used for heatup and cooldown rate calculations because it is more conservative.

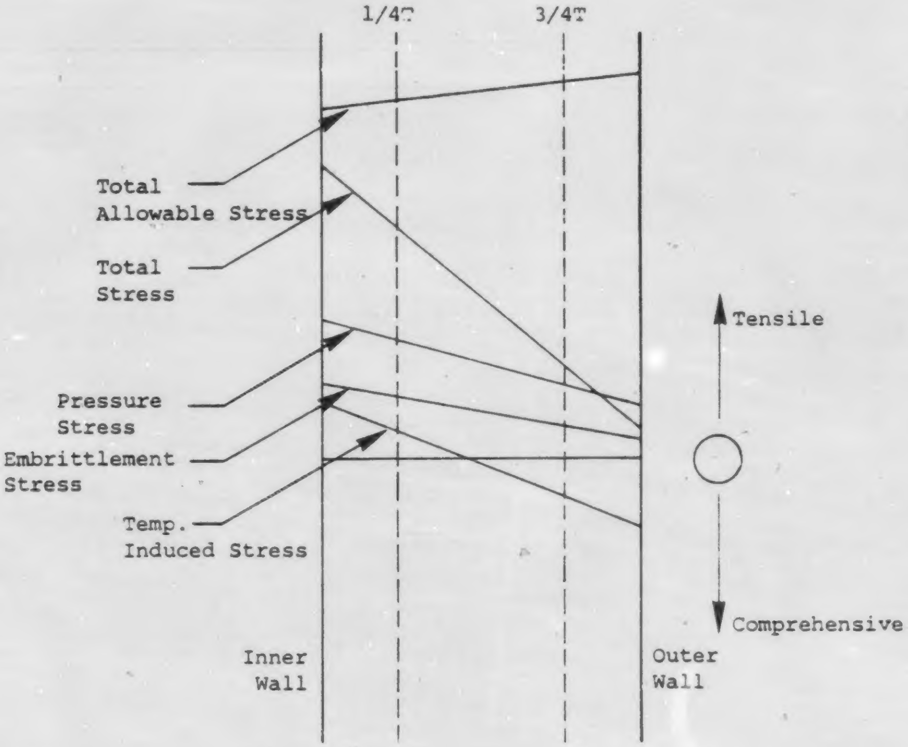

1/4T
3/4T
Total Allowable Stress
Total Stress
Pressure Stress
Embrittlement Stress
Temp. Induced Stress
Tensile
Comprehensive
Inner Wall
Outer Wall

Figure 30-7-3. Cooldown Stress Profile

Stresses Versus Material Properties

The foregoing discussion pointed out that pressure and temperature gradients introduce stresses on the reactor

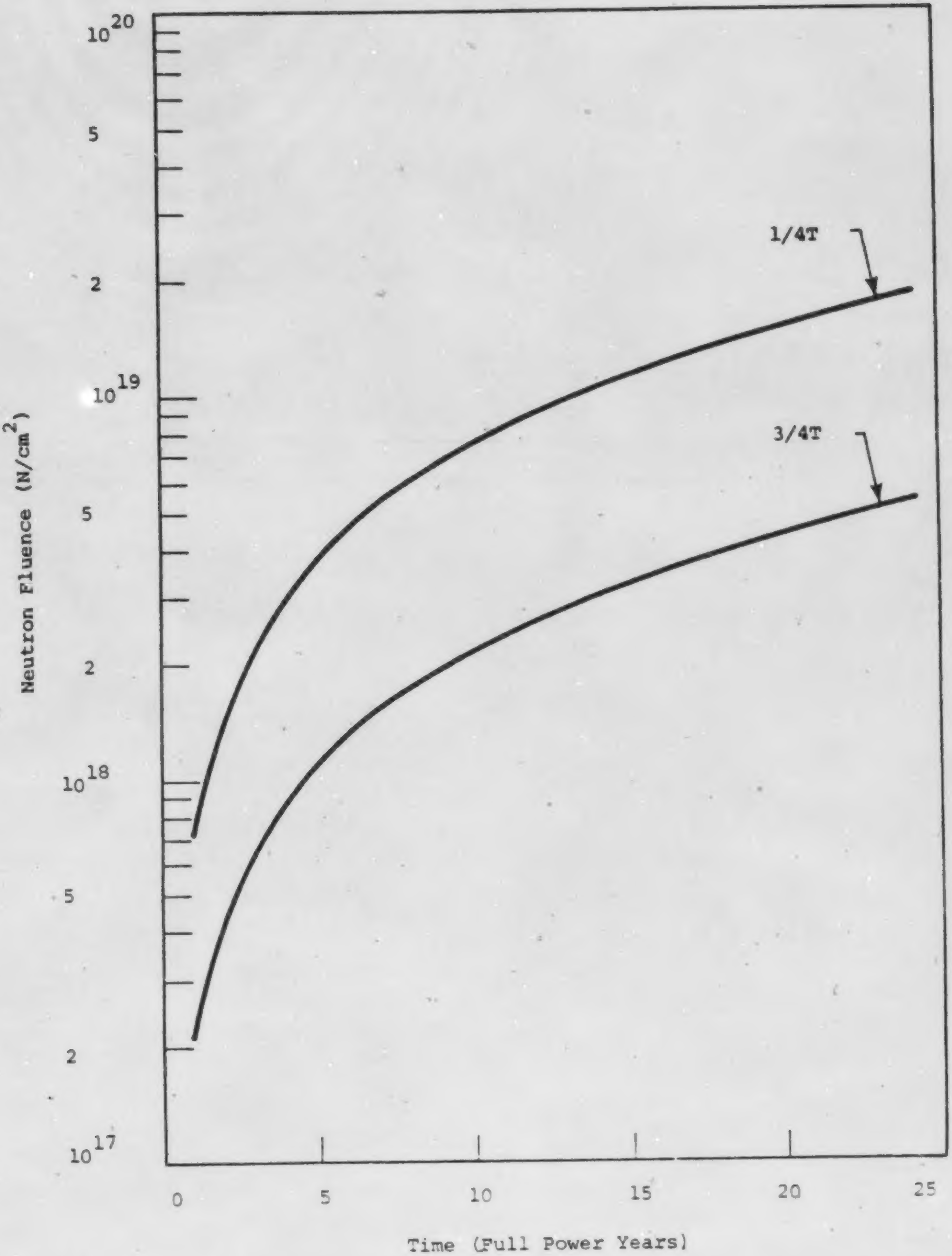


Figure 30-7-4. Typical Vessel Fluence at 1/4T and 3/4T as Function of Full Power Service Years (4 Loop Plant)

vessel. Stresses are categorized as primary, secondary, and local. Primary stress is a stress developed by the imposed loading. Secondary stress is a stress developed by the self constraint of the structure. Local (or peak stress) is the highest stress in the region under consideration. The basic characteristic of a local stress is that it causes no significant distortion but is objectionable because it may be a source of fatigue failure, brittle fracture, or stress corrosion cracking.

Several strength theories of failure have been developed based upon these types of stresses. Their purpose is to predict when failure will occur, assuming that the material behavior in a simple tension test is known and that failure is considered to be either yielding or rupture. Possible modes of metal failure are:

- excessive plastic deformation
- high strain fatigue
- corrosion fatigue
- stress corrosion
- brittle fracture
- excessive elastic deformation.

Of these failure modes, plastic deformation and brittle fracture are of primary concern for reactor vessels.

Elasticity of materials is an important consideration in choosing material to be used in a reactor vessel. Elasticity is that property of a material which measures ability to return to original shape or size after having been stretched, compressed, or deformed. A material which has a large amount of elasticity would be a rubber ball which can be compressed or stretched to certain limits and still return to its original shape. A material such as lead has very little elasticity because it takes very little force to cause a permanent change in its shape.

Elasticity is measured by the ratio of the stress called into play within the material by the action of deforming forces to the strain or changes in shape or dimensions. The measurement is the modulus of elasticity.

Formula 30-7-1

$$\text{Modulus of Elasticity} = \frac{\text{Stress}}{\text{Strain}} = \frac{\text{Force/Unit Area}}{\text{Elongation/Length}}$$

Stress is the force applied to an object per unit area. For example, a 1000 lb. force of tension on a steel bar 2 inches on a side would impose a stress of 1000 lbs/4 in^2 or 250 lbs/in^2.

Strain is a measure of the deformation of a body under stress. In the previous example, a 1000 lbs. force resulted in a 250 lb./in^2 stress. If this same steel bar were 10 inches long before the stress were applied and 10.15 inches long during the time in which the stress were applied, it would have experienced a strain of 0.15 in/10 or 0.015 in/in.

These two properties, stress and strain are used to construct a diagram by which the properties of a material may be examined. This diagram is called a stress-strain diagram. The stress-strain diagram is used to determine different elastic points possessed by a material under a stress. A typical diagram is shown in Figure 30-7-5.

Referring to the stress-strain diagram, the plot from 0 to B is a straight line, which indicates that stress is proportional to strain for small strains. This behaves according to Hooke's Law which states that: "The deformation of an elastic body is directly proportional to the magnitude of the applied force, provided the elastic limit is not exceeded." The elastic limit is reached at B after stresses greater than that at point B have been attained. This means that the metal no longer regains its

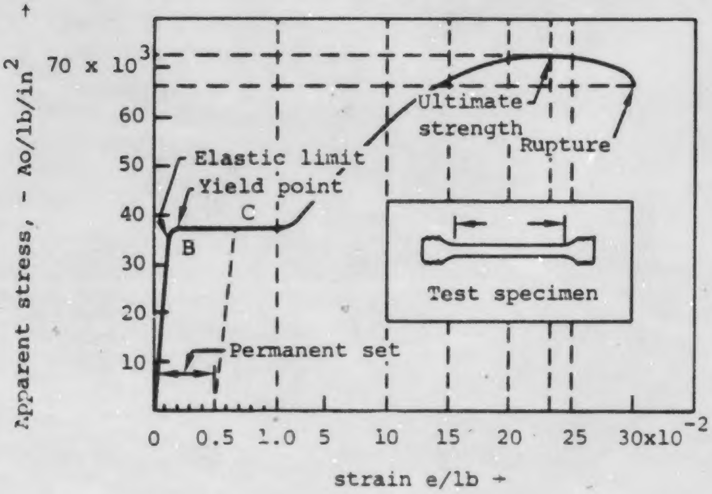


Figure 30-7-5. Typical stress-strain diagram for medium steel in tension. Note the change in scale of strain by a factor of 10 at the broken line.

original length when the distorting forces have been removed. If the tension is removed at C, the strain retraces the broken curve and the bar is left with a permanent set (plastic deformation). As the stress is increased beyond the elastic limit, the yield point is soon reached. At the yield point, a large increase in strain occurs with almost no increase in stress. In fact, when the yield point is reached, the bar appears to flow like an extremely viscous liquid. As the strain is further increased, the stress changes as shown in the figure until rupture occurs. The ultimate tensile strength is the highest point of the curve or the maximum apparent stress that the material can withstand. The ultimate strength is frequently slightly higher than the stress at rupture and may be much above the yield point, as is the case with steel.

It has been found that the yield point, ultimate stress, rupture point etc. are not constant, but rather are a function of the temperature. In fact there is a point (in temperature) below which almost all materials fail brittlely rather than ductilly as in the foregoing discussion. Brittle failure or fracture is one in which there is a failure of the material without any prior plastic deformation. An example of brittle fracture is glass breaking at room temperature.

Normal steel and other structural type metals have a great deal of plastic deformation before they fail. However, there has been a history of metal containers and structures which have failed as a result of brittle fracture.

In Boston, Mass. in 1919, a 2,300,000 gallon molasses tank fractured on a cold day and twelve men and four horses lost their lives in the disaster. This incident was isolated and it wasn't until World War II when interest in brittle fracture was greatly stimulated when 250 U.S. ships experienced brittle fracture in various degrees of severity. Nineteen of these ships broke in half. In each incident, the temperature was about 40° F.

When tensile specimens are tested at lower and lower temperatures, there exists a temperature at which the yield strength equals the ultimate strength. This is shown as NDT in Figure 30-7-8. At NDT, there is no measurable ductility. The point of Figure 30-7-6 labeled as NDT is called the nil ductility temperature, which is symbolized as T_{NDT}. Metallurgical variables, such as grain size, affect T_{NDT}. Therefore, testing is required to determine the T_{NDT} of a given material. The nil ductility temperature determined by testing is referred to as "reference temperature for nil ductility" and is symbolized by RT_{NDT}.

Brittle fracture is characterized by individual grains of the metal fracturing by "cleavage" of the crystal planes of the metal. Brittle fracture may start at nominal levels of stress provided certain other conditions are satisfied such as the following:

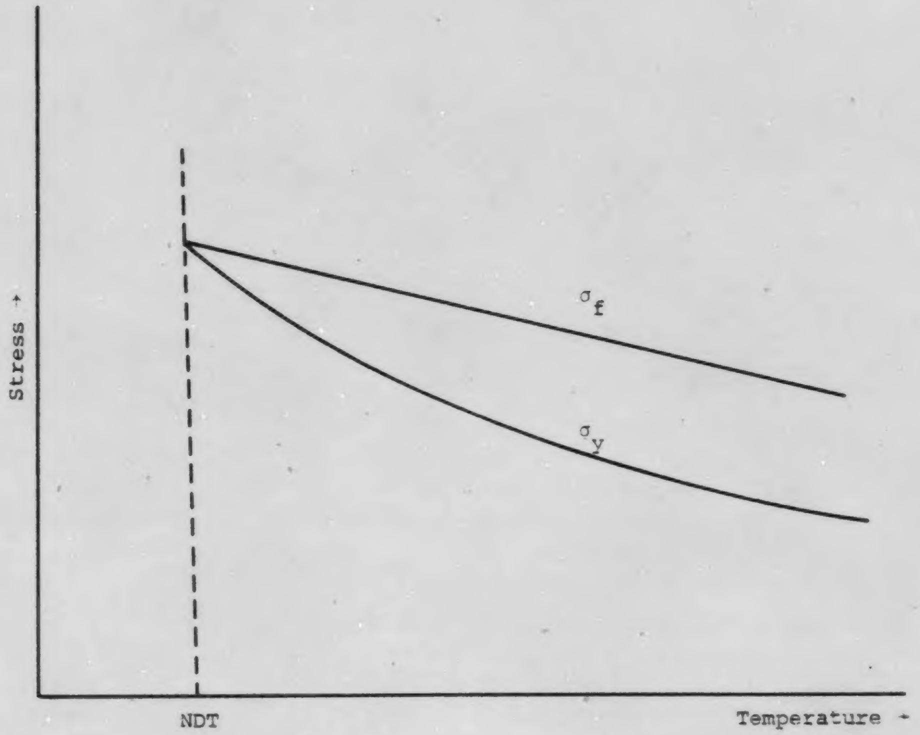


Figure 30-7-6. Stress vs. temperature curve showing plot of failure strength (σ_f) and yield strength (σ_y).

- a flaw such as a crack is present.
- a local stress of sufficient intensity to develop a small deformation at the crack tip is applied.
- a temperature exists which is low enough to promote cleavage fracture of the deformed metal crystals.

Neutron irradiation of the reactor vessel produces damage to the metal's crystalline lattice structure, which increases the yield strength of the material, but also increases the temperature at which brittle failure will occur. Because of this, the RT_{NDT} of the reactor vessel will increase over core life. An increase of 250°F is not uncommon. Figure 30-7-7 shows this variation and shows that it is also a function of the copper content of the carbon steel reactor vessel.

Since brittle failure must be avoided at all cost, the stresses imposed on the vessel from pressure and temperature gradients must be limited to a safe value. These considerations are used to establish temperatures above which the system may be pressurized and to establish heatup and cooldown curves for the reactor coolant system.

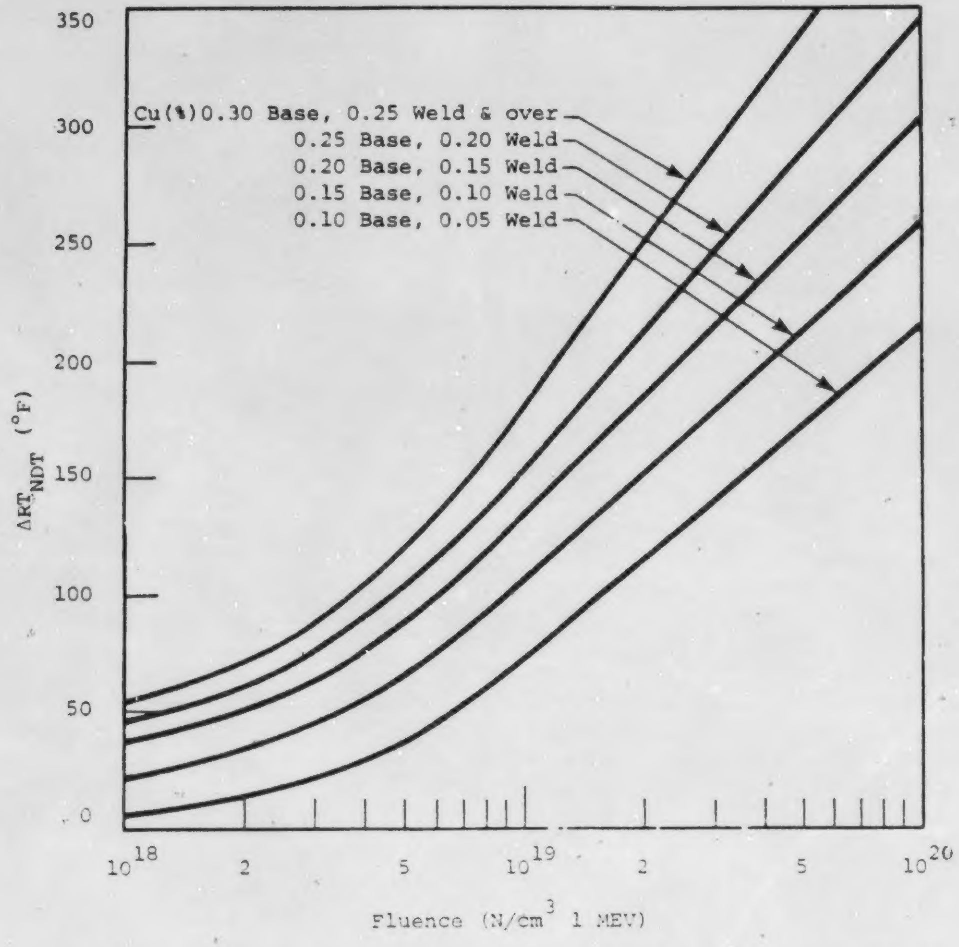


Figure 30-7-7. Effect of Fluence and Copper Content on Shift of RT_{NDT} for Reactor Vessel Steels Exposed to 550°F Temperature.

Operational Limits

Limits are imposed on reactor operation such that pressure and temperature induced stresses do not cause either plastic deformation or brittle fracture. These limits include allowance for the shift in RT_{NDT} caused by radiation embrittlement and also include a liberal safety margin. These limits are based on the existance of allowable flaws at 1/4T. Thus, if only allowable flaws are present and if temperature and pressure limits are observed, safe operation of the reactor vessel is assured.

Heatup and cooldown limits are applied specifically to avoid brittle fracture. These limits ensure that temperature is raised above RT_{NDT} prior to fully pressurizing the system.

A typical curve which establishes heatup limits for a PWR vessel is illustrated in Figure 30-7-8. Operation must be such that coolant pressure is not increased above the curve. This ensures that temperature is increased well above RT_{NDT} prior to fully pressurizing the system. The criticality limit shown in Figure 30-7-8 takes into account the maximum shift in RT_{NDT} due to radiation plus a liberal safety margin. The reactor core is not permitted to be taken critical until system temperature is above the criticality limit.

A typical cooldown curve for a PWR vessel is illustrated in Figure 30-7-9. As the reactor system is cooled, pressure must be lowered to remain under the curve.

Note, both Figure 30-7-8 and 30-7-9 are valid for 10 effective full power years (EFPY). Nominally a plant is designed for 40 years of service of which about 80% of the time it is "effectively" at 100% power. Hence a nuclear plant would normally operate for about 32 EFPY.

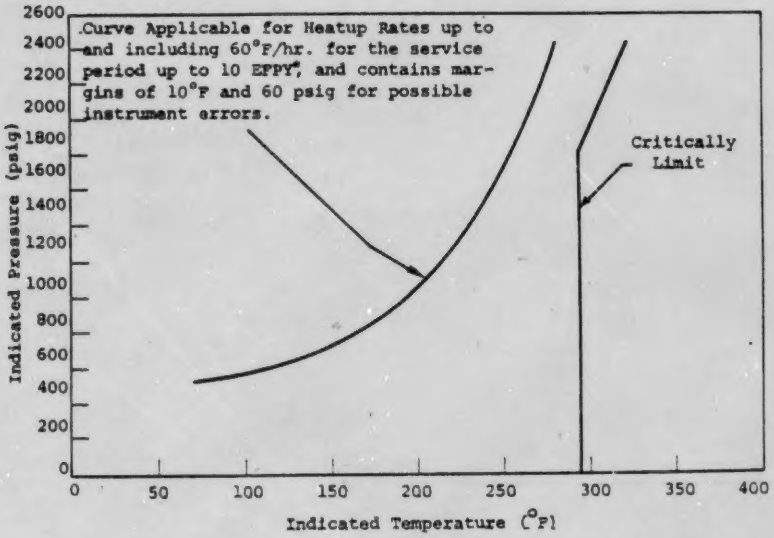


Figure 30-7-8. Reactor Coolant System-Heatup Curve (Typical)

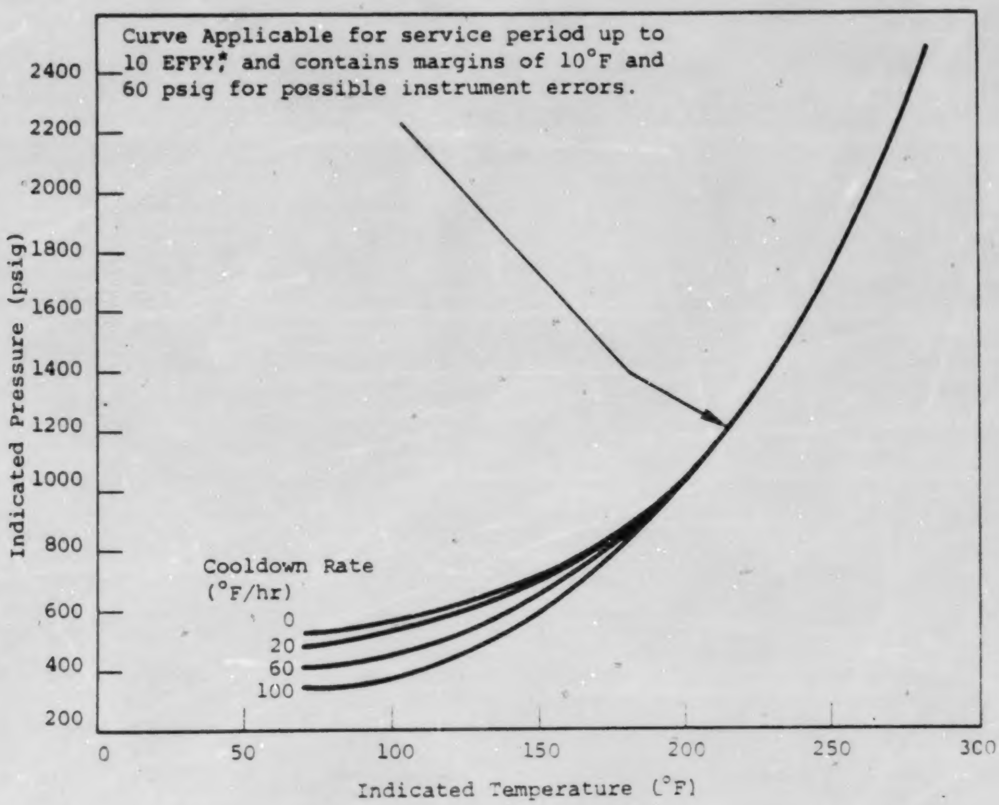


Figure 30-7-9. Typical Reactor Coolant System Cooldown Limitations.
*Note: EFPY refers to effective full power years.

DESIGN AND FABRICATION

Design

Reactor vessels are designed in accordance with provisions for Class I components of Section III of the ASME Boiler and Pressure Vessel Code. Class I components have the most stringent requirements applied. The design is documented in the form of a reactor vessel specification and associated drawings. The adequacy of the design is confirmed by stress analyses which analyze and report ability of the design to withstand static, dynamic, and thermal stresses including after irradiation. The reactor vessel specification and associated design drawings are used as procurement documents in the purchase of reactor vessels. These documents specify:

- materials to be used
- dimensions of overall size, wall thicknesses, and size and form for interfacing features such as nozzles, ledges, closure assembly, mechanism houses, instrumentation connections, lifting lugs, and support mounts.
- cladding material
- closure head assembly features
- special processing requirements such as welding and heat treatment
- destructive testing requirements such as tensile and impact testing.
- nondestructive testing requirements such as radiography and magnetic particle
- acceptance criteria for materials, processing, inspection and testing.

Suppliers of reactor vessels are required to strictly adhere to the requirements of the procurement documents and

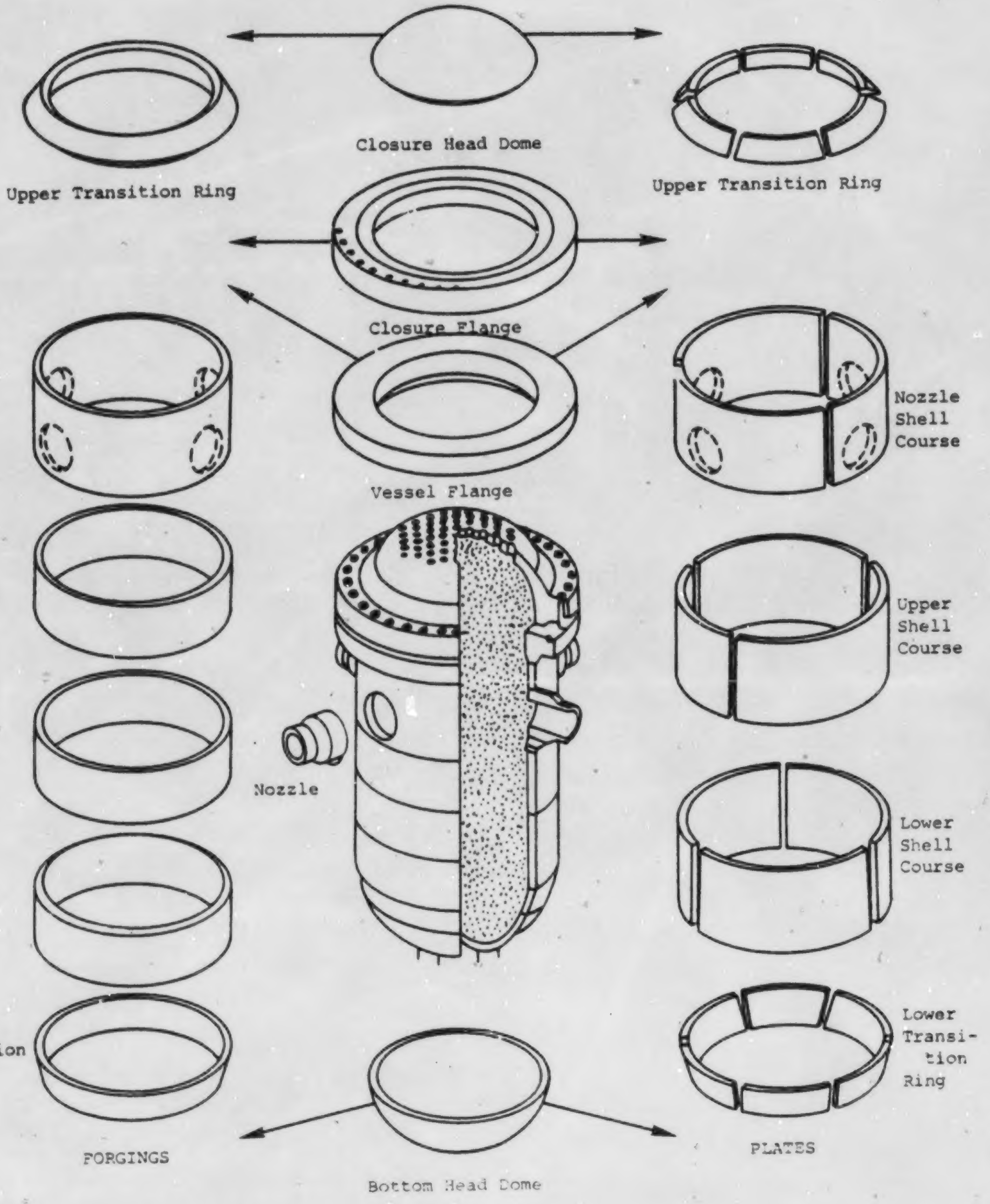

Closure Head Dome
Upper Transition Ring
Upper Transition Ring
Closure Flange
Vessel Flange
Vessel Flange
Nozzle Shell Course
Upper Shell Course
Upper Shell Course
Intermediate Shell Course
Nozzle
Lower Shell Course
Lower Shell Course
Lower Transition Ring
Lower Transition Ring
FORGINGS
PLATES
Bottom Head Dome

Figure 30-7-10. PWR Reactor Vessel Assembly Showing Forging and Plate-type Construction

to obtain customer approval of deviations therefrom. The supplier is also required to maintain and implement a quality assurance program which ensures compliance with procurement documents. The purchaser is responsible for evaluating the effectiveness of the supplier's quality assurance program and for ultimate acceptance of the reactor vessel.

Basic Fabrication

The reactor vessel is fabricated from a series of cylindrical sections called "shell courses" and from two hemispherically shaped heads. A typical PWR vessel is illustrated in Figure 30-7-10.

Referring to Figure 30-7-10, shell courses are typically rolled plate although forgings may be used. The plate segments are longitudinally welded to form a shell course. The shell courses are circumferentially welded to form the overall structure. The top and bottom heads are hemispherical and fabricated from a dome forging, transition ring, and flange. Head penetrations are provided for control rod drive mechanisms and thermocouple connections. The vessel flange is a forging which is welded to the nozzle shell course as depicted in Figure 30-7-10. The interior wall of the reactor vessel is completely clad with either stainless steel or inconel to resist corrosion by the reactor coolant. Critical machining steps are associated with nozzle and penetration locations, flange bolt holes, keyways for alignment of closure head to vessel assembly, flange mating surfaces, and interior support ledges and keyways.

MATERIALS

Material Specifications

The American Society of Mechanical Engineers (ASME) publishes material specifications as Part II of the ASME Boiler and Pressure Vessel Code. Most of these specifications are identical to material specifications published by the American Society for Testing of Materials (ASTM). The reactor vessel design specification and drawings stipulate for each part the applicable material specification and any modifications, additions, or deletions to the material specification for the specific design. The reactor vessel supplier orders materials from melters and metal finishers to these stipulated material requirements which will permit meeting final dimensions as given by design drawings. Each material specification delineates requirements, as applicable, for:

- melting processes
- heat treating
- chemical analysis
- destructive testing
- nondestructive testing
- marking
- certification

The material supplier normally performs all required inspections and tests on the material and reports the results to the reactor vessel fabricator. However, the fabricator may elect to perform any or all material inspections and tests after receipt of the material. In either case, the quality assurance program must ensure that material meets specified requirements prior to releasing the material for fabrication.

Chemical Analysis

Chemical analysis confirms that specified alloying ingredients are present in the correct percentage. Also, where undesirable constituents, such as copper, have imposed limits, chemical analysis confirms compliance with such limits. Each material specification stipulates the chemical requirements to be met by any heat of material to that specification. In addition, the reactor vessel fabricator must include in the order for materials any additional chemical requirements and limitations imposed by the design documents for the specific reactor vessel. An example of chemical requirements based on material specification SA-533 is given in Table 30-7-1. Material processing by the reactor vessel fabricator does not alter the chemical composition of starting materials.

Table 30-7-1

Example Chemical Requirements

Alloy Material	Composition (percent)
Carbon	0.25 max
Manganese	1.15 → 1.50
Phosphorous	0.035 max.
Sulphur	0.040 max.
Silicon	0.15 → 0.30
Molybdenum	0.45 → 0.60
Nickel	0.40 → 0.70
Copper	0.12 max.

Mechanical Tests

Mechanical tests confirm that the strength and ductility requirements imposed by design are met by the materials used to fabricate the pressure vessel. Mechanical tests are destructive in nature and are therefore also termed destructive tests.

The mechanical properties of metals are affected by chemical constituents, heat treatment, and metal deforming processes such as rolling, bending, and forging. Thus, mechanical tests are performed by the material supplier after all finishing and heat treatment operations have been completed. However, the reactor vessel fabricator will of necessity subject the material to stress relief heat treatment of welded joints. The fabricator may also bend plate sections to form shell course segments. These processes by the fabricator have potential for altering the mechanical properties of materials. Thus, the fabricator must also perform mechanical testing.

Test specimens are taken from a location of 1/4T where T equals material thickness. Specimens are taken from either production material or from separate test pieces which are from the same heat and which receive the same finishing and heat treatment as the production lot. Because of the destructive nature of the tests, the reactor vessel fabricator processes control material samples in conjunction with vessel fabrication. These controlled samples receive the same bending and heat treatment as their corresponding reactor vessel parts. Upon completion of fabrication, specimens are taken from the control samples and tested to verify that mechanical properties are still within limits.

Mechanical test methods include tensile, drop weight, Charpy V-notch, and bend tests. Except for bend tests, these tests are applied to vessel materials and to weld material qualifications. Descriptions of these tests are as follows:

- tensile test - The tensile test is a static test that uses the well known tensile test machine which pulls the specimen until it fails. The machine uses pressure detectors and strain gages to measure and plot the elongation of the specimen versus the load applied to it. Since the applied load and the cross section of the specimen are known, the yield and ultimate stresses of the specimen are readily determined. The tensile test machine develops the stress-strain curve illustrated in Figure 30-7-5.

- drop weight test - The drop weight test is a dynamic test which determines T_{NDT}. A test specimen having a preplaced crack in a weld buildup or the underside is placed horizontally in a test fixture. The fixture permits a free-falling weight to strike the test specimen. The specimen is cooled to a preselected temperature and drop weight tested. Crack propagation, if any, is ductile above the nil ductility temperature. The test is performed at consecutively lower temperatures of the test specimen until T_{NDT} is determined by the occurrence of brittle fracture.
- Charpy V-notch - The Charpy V-notch test (C_N) is a dynamic test which uses a free swinging weighted pendulum for striking the test specimen. The test specimen is a rectangular bar with a "V" shaped notch. The specimen is mounted such that its notch is on the opposite side of the impact from the pendulum. The specimen is cooled to a temperature not greater than $T_{NDT} + 60^{\circ}F$ and impact tested. The machine measures the energy absorbed by the specimen and the broken specimen is examined for lateral expansion. If absorbed energy is at least 50 ft-lb and lateral expansion is at least 35 mils, ductile failure has occurred and RT_{NDT} equals T_{NDT}. If absorbed energy or lateral expansion is less than these limits, additional specimens are tested at

consecutively higher temperatures until both limits are met. In such case, RT_{NDT} equals T_{NDT} plus the increase in temperature from the initial test.

Example

Problem #1: Determine RT_{NDT}

Given:

$T_{NDT} = 15^{\circ}F$ as determined by drop weight testing

C_V at 70°F yields 62 ft-lb absorbed energy and 38 mils lateral expansion

Solution:

$RT_{NDT} = T_{NDT} = 15^{\circ}F$ because C_V limits are met

Problem #2 Determine RT_{NDT}

Given:

$T_{NDT} = 15^{\circ}F$

C_V at 70°F yields 20 ft-lb and 10 mils

C_V at 75°F yields 35 ft-lb and 12 mils

C_V at 80°F yields 52 ft-lb and 36 mils

Solution:

$$RT_{NDT} = T_{NDT} + T_{increase} = 15^{\circ}F + (80^{\circ}F - 70^{\circ}F)$$
$$= 15^{\circ}F + 10^{\circ}F = 25^{\circ}F$$

- bend tests - The bend test is a static test which physically bends a rectangular test specimen around a mandrel of known radius. The bent specimen is visually examined (typically at 5x or 10x magnification) for cracks and voids. This test determines ductility and freedom from flaws and it is used for testing welding procedure qualification test pieces.

Heat Treatment

Heat treatment of materials is performed by the material manufacturer and the reactor vessel fabricator. Heat treatment by the material manufacturer is that required by the material specification. The heat treatment specified is that which will produce the desired mechanical properties in the material. The material manufacturer must include in the material certification the type of heat treatment used and, if specified by the material specification, the temperature and time at temperature seen by the material. The fabricator performs stress relief heat treatments after welding operations. Time-temperature chart recordings are required for each post weld heat treatment.

Nondestructive Examination of Materials

All pressure retaining material is nondestructively examined for unacceptable flaws. In most cases, volumetric examination is required. Volumetric examination is by either radiography (RT) or ultrasonic (UT) examination. Surface examination, when required, is by either magnetic particle (MT) or liquid penetrant (PT) examination. MT is used for magnetic materials and PT for nonmagnetic materials. Table 30-7-2 lists typical requirements.

Table 30-7-2

Typical Nondestructive Examinations

Material Type	RT	UT	MT or PT	
Plate		X		
Weld Repair of Plate	X		X	
Forgings		X	X	
Coarse grain & complex shape forgings	X		X	
Weld Repair of Forgings	X	(1)	X	
Bolting		(2)	(3)	

Notes: (1) UT of weld repair of certain forgings is permitted in lieu of RT
(2) UT of bolting materials greater than 2 inches is required
(3) MT or PT of bolting materials of 1 to 2 inches is required

Weld Repair of Materials

Unacceptable flaws found by nondestructive examination of materials is repaired by welding except that repair of bolting material is not permitted. Repair procedures must include an examination to verify removal of flaws and to accept the completed weld repair. Verification of flaw removal is by MT or PT of the excavated area. Acceptance of the repair weld is by the method listed in Table 30-7-2. The welding repair procedure and the welder must be qualified. Such qualification is based on the testing of qualification specimens which are welded in accordance with the procedure.

Certification by Material Manufacturer

The material manufacture certifies materials by submittal of a Certified Material Test Report. This certification affirms that the contents of the report are correct and accurate and that all test results and operations are in compliance with the material specification and requirements invoked by the material purchase order. Where the material manufacturer subcontracts for starting material or processing a Certified Material Test Report from each subcontractor and a Certified Material Test Report for only the operations performed by the material manufacturer is permissible. While there is no mandatory format, Certified Material Test Reports identify (1) material specification, grade, class, and condition of material, (2) heat or lot number of materials represented by the certification, (3) results of chemistry analysis for each constituent having a specified range or limit, (4) type and results of each required mechanical test, (5) method of heat treatment and, when specified, heat treatment temperature and time (6) radiographs of weld repairs, and (7) other data requested by the purchase order.

Marking of Material

Material is marked by the material manufacturer with the applicable specification number, grade of material and heat or lot number. Except for small products having less than 1 inch in any direction for the application of marking, each piece of material is marked. For small products, the package or container is marked. Such marking permits direct correlation with the Certified Material Test Report representing the material.

FABRICATION PROCESSING

Purpose

The reactor vessel fabricator prepares processing instructions which identify all necessary manufacturing, inspection, and test steps in the proper sequence for the fabrication of the vessel in accordance with design. Such processing is typically prepared by a product engineering department and approved by a quality engineering group. In addition, an outline of the processing may be required by the contract to be submitted to the Purchaser for approval. The processing has the following purposes:

- identify all necessary steps for fabrication, inspections, and tests.
- identify correct sequences for fabrication, inspection and tests.
- permit application of hold points for customer inspections

Typical Processing

Review of Figure 30-7-10 reveals that many parts comprize the reactor vessel. Starting from plates and forgings, the fabricator sizes, forms, welds, heat treats, and machines to arrive sequentially at finished pieces, subassemblies, assemblies, and the final component. The overall processing is illustrated in Figure 30-7-11.

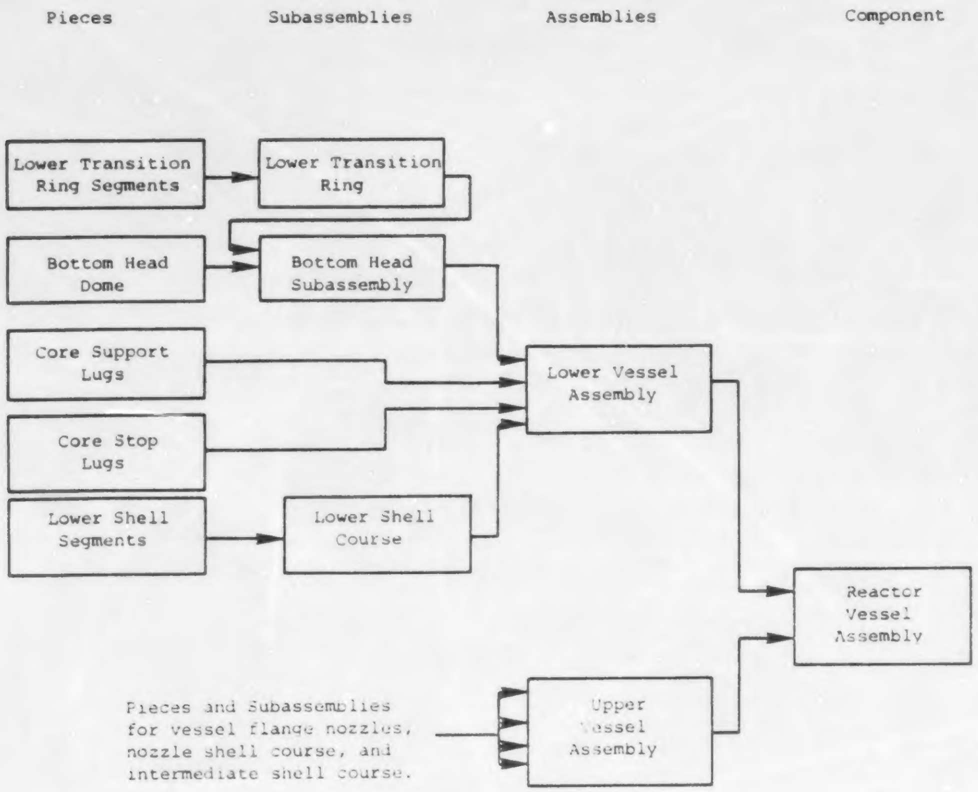

Pieces
Subassemblies
Assemblies
Component
Lower Transition Ring Segments
Lower Transition Ring
Bottom Head Dome
Bottom Head Subassembly
Core Support Lugs
Core Stop Lugs
Lower Shell Segments
Lower Shell Course
Lower Vessel Assembly
Reactor Vessel Assembly
Pieces and Subassemblies for vessel flange nozzles, nozzle shell course, and intermediate shell course.
Upper Vessel Assembly

Figure 30-7-11. Major Processing Phases for Vessel Without Closure Head Assembly

Processing instructions are prepared for each block identified in Figure 30-7-11. In this manner, detailed instructions are provided for manufacture, inspection, and test, as required, for each piece, subassembly, assembly, and final component. Such instructions must implement the requirements of the ASME Boiler and Pressure Vessel Code for Class 1 components. Key features of Code requirements are:

- material identity marking is maintained at all times
- preheat is necessary prior to thermal cutting or

welding

- forming processes (e.g. bending plate to form) are qualified by forming of test specimens.
- dimensional and form tolerances of drawings are verified by inspection
- fitting and aligning of parts to be joined by welding is verified by inspection
- welding procedures are qualified
- welders are qualified
- welds are nondestructively examined (mostly by radiography and magnetic particle examination)
- nondestructive examination personnel are qualified and use approved procedures
- weld repairs are made by qualified welding procedures and welders and are examined by qualified persons.
- cleaning steps and inspections for cleanliness are used at key steps such as prior to load in a heat treatment furnace.
- post weld heat treatments are performed by approved procedures and time-temperature recordings are made.
- status of inspections and tests is evident at all times
- the completed component is hydrostatically tested
- the completed component is certified by the fabricator.

Component Hydrostatic Test

The hydrostatic test is the final nondestructive test of the completed reactor vessel. It is a pressurization of the completed reactor vessel at 1.25 times the design pressure. It is performed to confirm the integrity of the reactor vessel and to verify the results of all the other non-destructive tests performed on the vessel. The hydrostatic test is performed at a temperature of $60^{\circ}F$ above the measured RT_{NDT} for the reactor vessel.

The fabricator uses blind flanges and plugs to close all openings. Those on high points are fitted with vents to permit venting of all air as the vessel is filled with water. Direct reading pressure gages are installed which have a range of between 1½ to 4 times the test pressure. Pressure gages are calibrated prior to each test or at two week intervals if they are used in a series of tests. Overpressure protection is typically provided by relief valves.

After filling and venting, the water pressure is raised to test pressure by a positive displacement pump. Test pressure is held for a minimum of ten minutes after which visual examination for leaks is performed. During this visual examination, pressure may be lowered to 3/4 of test pressure. Any leak, other than from temporary seals, is cause for rejection.

Component Nameplate and Certification

Reactor vessel fabricators must possess an "N" stamp for Class 1 components. The N stamp is obtained by application to the American Society of Mechanical Engineers (ASME). The ASME reviews and audits the fabricators quality assurance program and issues a certificate of N stamp authorization upon acceptance of the fabricator's quality assurance program. This permits the fabricator to stamp the vessel name plate and to certify the vessel to the Code.

A nameplate is attached to each reactor vessel. This nameplate has sufficient information to permit correlation with the Data Report Form representing the vessel. As a minimum, the nameplate identifies:

- "N" symbol which is N_1 for reactor vessels
- component Class which is Class 1 for reactor vessels
- name of manufacturer

- design pressure and coincident temperature
- manufacturer's N Certificate serial number
- year of manufacture.

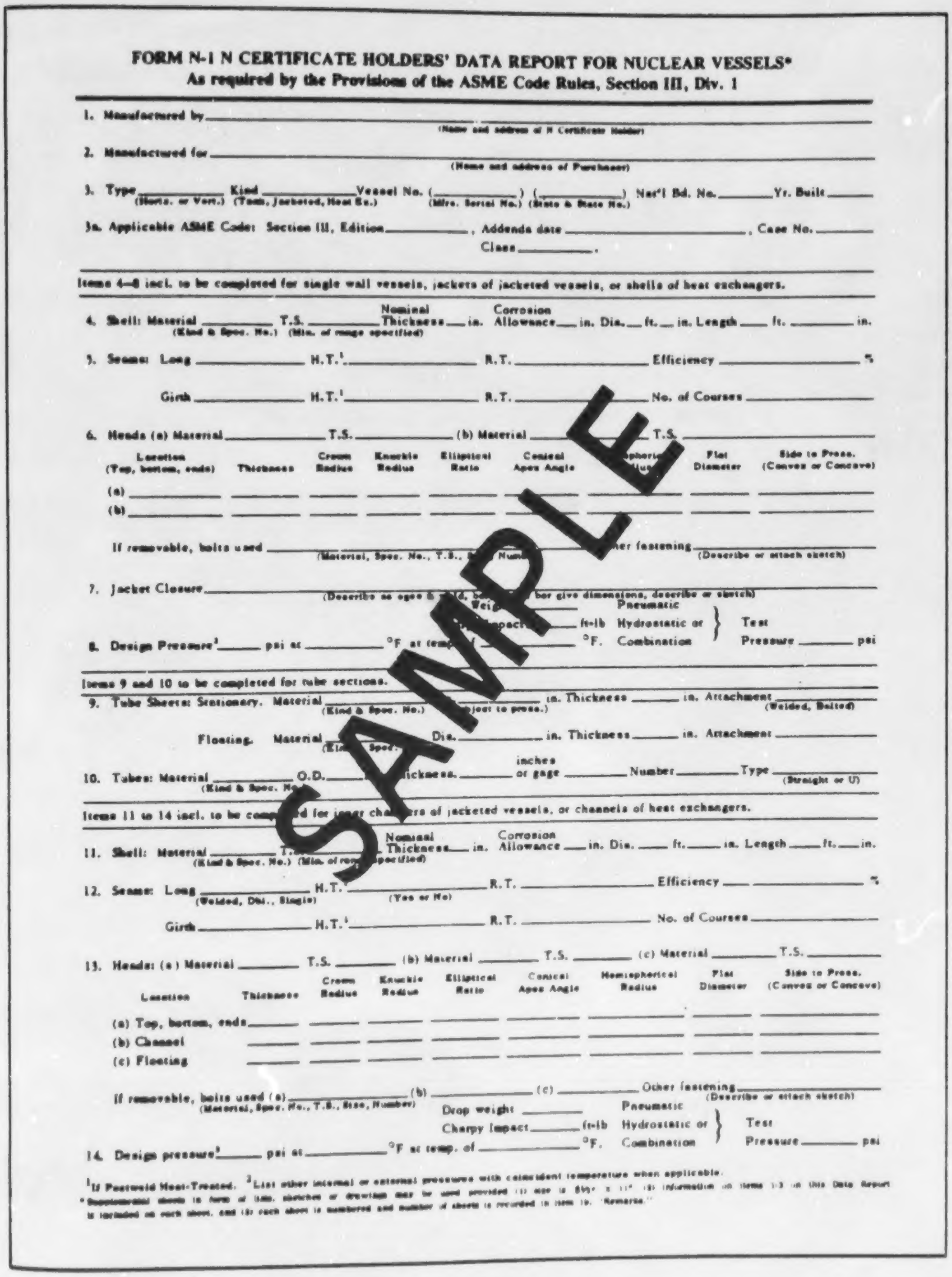
Certification of the reactor vessel is made by the fabricator by Data Report Form N-1. This form, which is illustrated in Figure 30-7-12, is supplemented by lists and drawings such that the Data Report provides sufficient information to permit retrieval of all design, fabrication, inspection, and test documents, procedures, and records. The fabricator also attaches Certified Material Test Reports for all pressure boundary materials used in the reactor vessel. These are reports completed by the fabricator for those materials whose properties were affected and determined by the fabrication process, and those submitted by the material manufacturer for materials whose properties were not affected by the fabrication process.

RECEIPT AND INSTALLATION

Owner's Acceptance

The owner of the nuclear power plant ultimately accepts the delivered reactor vessel. Therefore, the owner, i.e., the nuclear utility, establishes a program which develops a basis for acceptance. This program is typically comprized of audits and inspections.

Quality assurance audits by the utility are typically performed of the reactor vessel design agency and the reactor vessel fabricator. In addition, the utility may accompany these contractors on their audits of subcontractors. These audits determine that an adequate quality assurance program is implemented and is effective in assuring that reactor vessel design, fabrication, inspection, and test operations are complying with Code requirements.



FORM N-1 N CERTIFICATE HOLDERS' DATA REPORT FOR NUCLEAR VESSELS*
As required by the Provisions of the ASME Code Rules, Section III, Div. 1

1. Manufactured by ____________________ (Name and address of N Certificate Holder)

2. Manufactured for ____________________ (Name and address of Purchaser)

3. Type ________ (Horiz. or Vert.) Kind ________ (Tank, Jacketed, Heat Ex.) Vessel No. (________) (Mfrs. Serial No.) (________) (State & State No.) Nat'l Bd. No. ______ Yr. Built ______

3a. Applicable ASME Code: Section III, Edition ________, Addenda date ________, Case No. ______ Class ________.

Items 4–8 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers.

4. Shell: Material ________ (Kind & Spec. No.) T.S. ________ (Min. of range specified) Nominal Thickness ___ in. Corrosion Allowance ___ in. Dia. ___ ft. ___ in. Length ___ ft. ______ in.

5. Seams: Long ________ H.T.[1] ________ R.T. ________ Efficiency ________ %

Girth ________ H.T.[1] ________ R.T. ________ No. of Courses ________

6. Heads (a) Material ________ T.S. ________ (b) Material ________ T.S. ________

Location (Top, bottom, ends)	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	[illegible]pheri[illegible] [illegible]ius	Flat Diameter	Side to Press. (Convex or Concave)
(a) ________	________	________	________	________	________	________	________	________
(b) ________	________	________	________	________	________	________	________	________

If removable, bolts used ________ (Material, Spec. No., T.S., [illegible] Num[illegible]) [illegible]her fastening ________ (Describe or attach sketch)

7. Jacket Closure ________ (Describe as ogee & [illegible]d, b[illegible] bar give dimensions, describe or sketch)

Wei[illegible] ______ [illegible]pact ______ ft-lb Pneumatic Hydrostatic or Combination } Test Pressure ______ psi

8. Design Pressure[2] ______ psi at ______ °F at tem[illegible] ______ °F.

Items 9 and 10 to be completed for tube sections.

9. Tube Sheets: Stationary. Material ________ (Kind & Spec. No.) ________ ([illegible]ject to press.) in. Thickness ______ in. Attachment ________ (Welded, Bolted)

Floating. Material ________ (Ki[illegible] Spec.[illegible]) Dia. ________ in. Thickness ______ in. Attachment ________

10. Tubes: Material ________ (Kind & Spec. No.) O.D. ______ [illegible]ickness ______ inches or gage ______ Number ______ Type ________ (Straight or U)

Items 11 to 14 incl. to be comp[illegible]d for i[illegible]r cha[illegible]rs of jacketed vessels, or channels of heat exchangers.

11. Shell: Material ________ (Kind & Spec. No.) T.[illegible] ________ (Min. of ran[illegible] specified) Nominal Thickness ___ in. Corrosion Allowance ___ in. Dia. ___ ft. ___ in. Length ___ ft. ___ in.

12. Seams: Long ________ (Welded, Dbl., Single) H.T.[1] ________ (Yes or No) R.T. ________ Efficiency ________ %

Girth ________ H.T.[1] ________ R.T. ________ No. of Courses ________

13. Heads: (a) Material ________ T.S. ________ (b) Material ________ T.S. ________ (c) Material ________ T.S. ________

Location	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Press. (Convex or Concave)
(a) Top, bottom, ends	________	________	________	________	________	________	________	________
(b) Channel	________	________	________	________	________	________	________	________
(c) Floating	________	________	________	________	________	________	________	________

If removable, bolts used (a) ________ (Material, Spec. No., T.S., Size, Number) (b) ________ (c) ________ Other fastening ________ (Describe or attach sketch)

Drop weight ______ Charpy Impact ______ ft-lb Pneumatic Hydrostatic or Combination } Test Pressure ______ psi

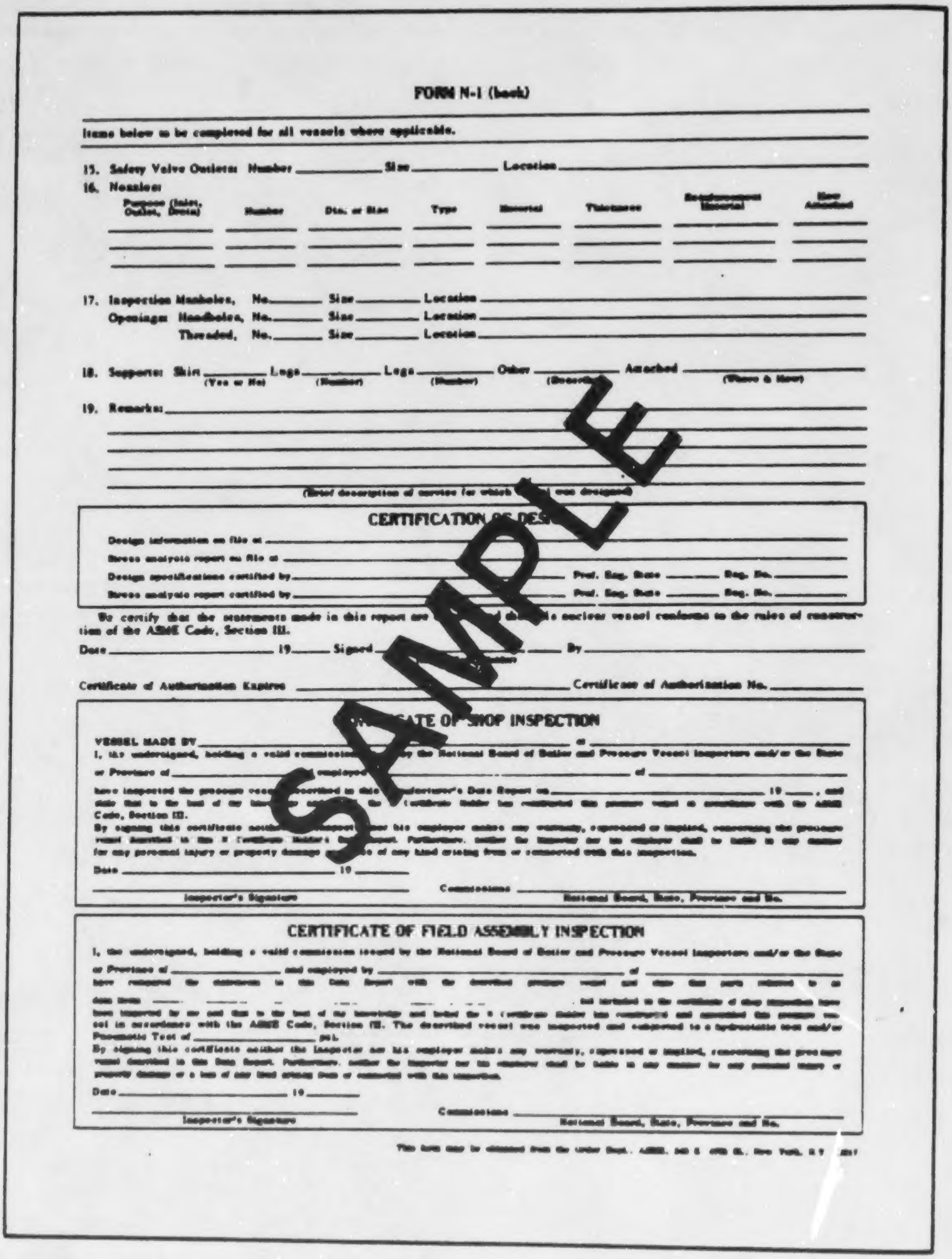
14. Design pressure[2] ______ psi at ______ °F at temp. of ______ °F.

[1] If Postweld Heat-Treated. [2] List other internal or external pressures with coincident temperature when applicable.

*Supplemental sheets in form of lists, sketches or drawings may be used provided (1) size is 8½" x 11", (2) information in items 1-3 on this Data Report is included on each sheet, and (3) each sheet is numbered and number of sheets is recorded in item 19, "Remarks."

SAMPLE

Figure 30-7-12. Sample Form N-1



FORM N-1 (back)

Items below to be completed for all vessels where applicable.

15. Safety Valve Outlets: Number ______ Size ______ Location ______

16. Nozzles:

Purpose (Inlet, Outlet, Drain)	Number	Dia. or Size	Type	Material	Thickness	Reinforcement Material	How Attached

17. Inspection Manholes, No. ______ Size ______ Location ______

Openings: Handholes, No. ______ Size ______ Location ______

Threaded, No. ______ Size ______ Location ______

18. Supports: Skirt ______ (Yes or No) Lugs ______ (Number) Legs ______ (Number) Other ______ (Describe) Attached ______ (Where & How)

19. Remarks: ______

(Brief description of service for which vessel was designed)

CERTIFICATION OF DESIGN

Design information on file at ______

Stress analysis report on file at ______

Design specifications certified by ______ Prof. Eng. State ______ Reg. No. ______

Stress analysis report certified by ______ Prof. Eng. State ______ Reg. No. ______

We certify that the statements made in this report are correct and that this nuclear vessel conforms to the rules of construction of the ASME Code, Section III.

Date ______ 19 ______ Signed ______ By ______

Certificate of Authorization Expires ______ Certificate of Authorization No. ______

CERTIFICATE OF SHOP INSPECTION

VESSEL MADE BY ______ at ______

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ and employed by ______ of ______ have inspected the pressure vessel described in this Manufacturer's Data Report on ______ 19 ______, and state that to the best of my knowledge and belief, the N Certificate Holder has constructed this pressure vessel in accordance with the ASME Code, Section III.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this N Certificate Holder's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ 19 ______

______ Inspector's Signature

Commissions ______ National Board, State, Province and No.

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ______ and employed by ______ of ______ have compared the statements in this Data Report with the described pressure vessel and state that parts referred to as data items ______, not included in the certificate of shop inspection, have been inspected by me and that to the best of my knowledge and belief the N Certificate Holder has constructed and assembled this pressure vessel in accordance with the ASME Code, Section III. The described vessel was inspected and subjected to a hydrostatic test and/or Pneumatic Test of ______ psi.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ______ 19 ______

______ Inspector's Signature

Commissions ______ National Board, State, Province and No.

This form may be obtained from the Order Dept., ASME, 345 E. 47th St., New York, N.Y. 10017

SAMPLE

Figure 30-7-12   Sample Form N-1 (continued)

Inspections are performed at the sites of the designer and fabricator and at the power plant site upon receipt of the reactor vessel. These inspections are planned to address the significant features which are critical to the quality of the reactor vessel. They include the inspection methods of record review, visual inspection, witnessing of processing and testing, and dimensional inspection. Items subject to inspection include:

- reactor vessel specification and design drawing
- stress analysis reports
- certified material test reports
- qualifications of welding procedures and welders
- control material specimens
- heat treatment recordings
- qualifications of nondestructive examination personnel
- inspection and test records
- control of nonconformances
- final interfacing dimensions
- hydrostatic testing
- Data Report Form N-1

Receipt Inspection

Reactor vessels are shipped by rail (or barge) to the nuclear power plant site. The vessels are attached to skids which are fixed to flat bed rail cars. All openings are sealed with temporary plugs and seals to maintain internal cleanliness. Thus, little is available for inspection upon receipt. This is why utility inspection is performed at source of manufacture.

Receipt inspection of reactor vessels typically consists of visual inspection of externals and review of Data Report forms. The visual inspection verifies name plate data and presence and tightness of seals in the various openings and determines if the vessel or its skid has shifted in transit. If there is evidence of movement between the vessel and its mountings, the cause is corrected and visual inspection is made for evidence of damage to the vessel.

Upon satisfactory completion of receipt inspection, the inspector tags the vessel as accepted and issues an inspection report. However, if a nonconformance is noted, the inspector tags the vessel as nonconforming and issues a nonconformance report.

Installation

The reactor vessel is one of the first components installed in the containment building. Optical tooling may be used for verifying location and form of mounts and for verifying orientation of the vessel on its mounts. Temporary seals are left in place until such time as piping, tubing, and control drive mechanisms are joined to the vessel.

After the primary coolant system has been installed and prior to fuel load into the vessel, a system hydrostatic test is conducted. This test not only tests the reactor vessel but also all connections to it which were made during installation.

The hydrostatic test is performed in essentially the same manner as that performed by the fabricator. However, the system pressure and temperature design limitations apply. Typical limitations for hydrostatic testing of a PWR are given by the pressure-temperature curve in Figure 30-7-13. For the system represented by the figure, coolant temperature must be greater than 135°F prior to pressurizing above 900 psig.

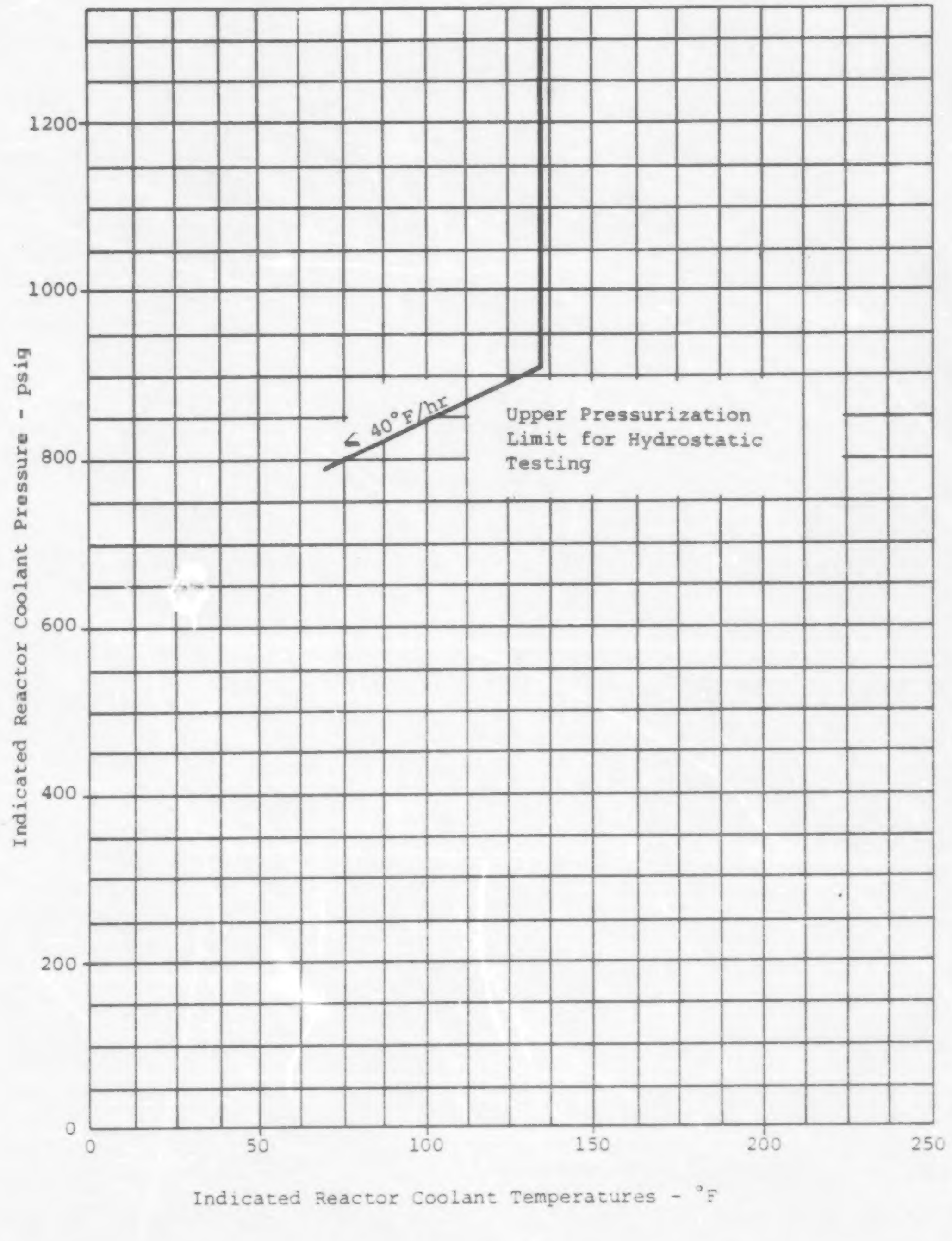


Figure 30-7-13. Hydrostatic Testing Limitations

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EXERCISES

The following exercises serve to reinforce the material presented in this module.

A. Perform the following exercises as indicated.

1. Perform one or more of the field trips outlined in the Procedures section of this module.

2. Prepare a report on each of the field trips taken as suggested in the Procedures section of this module.

Answer the following questions as indicated.

3. Explain why the failure or rupture of the reactor vessel could have catastrophic consequences on the reactor core protection and radiation safety of the nuclear power station.

4. Briefly explain how the reactor vessel is constructed. In your description include the following terms:
   a. shell courses
   b. transition rings
   c. head domes
   d. plates
   e. forgings

5. Explain why a low alloy steel consisting of iron alloyed with molybdenum, manganese, and having a low carbon content is used for reactor vessel construction.

6. The various nondestructive testing methods used to inspect the vessel consist of:
   a. Visual Inspection
   b. Magnetic Particle Testing
   c. Dye Penetrant Examination
   d. Radiographic or X-ray Inspection
   e. Ultrasonic Testing
   f. Hydrostatic Testing

   Briefly describe each technique.

B. Answer the following questions as either true or false in the following exercises. An answer key is provided following this set of exercises.

____ 1. Pressure and temperature create, stress on the reactor vessel. So long as the vessel temperature is above its nil-ductility temperature, the vessel will exhibit a normal amount of strain as pressure is applied to it.

____ 2. The steel used for fabrication of the reactor vessel is a low alloy steel consisting of iron alloyed with molybdenum, manganese, and having a low carbon content because this particular alloy is extremely resistant to fast neutron irradiation damage.

____ 3. Brittle fracture can occur when three necessary conditions are satisfied: (1) a flaw such as a crack is present, (2) a stress of sufficient intensity to develop a small deformation at the crack tip is applied, (3) a temperature low enough to promote cleavage is the crystal planes is achieved.

____ 4. Destructive tests which are performed on the reactor vessel materials are: (1) tensile test, (2) Charpy V-notch test, (3) dropweight test, (4) bend test.

____ 5. The tensile test is a static type of test employing a machine which bends a specimen until it cracks.

____ 6. The Charpy V-notch Test is a dynamic test in which a small rectangular beam containing a "V" shaped notch is cooled and struck by a single blow of a pendulum on a point opposite the notch. The amount of energy required to fracture the specimen is determined and this value is plotted as a function of the test temperature.

____ 7. The Dropweight Test is a destructive test using a rectangular beam specimen upon which a pre-placed crack is a brittle weld has been placed. The specimen is then heated to the ΔRT_{NDT} value of $285^{\circ}F$ (equivalent to 32 effective-full-power years of operation) and supported in a test fixture and struck by a free falling weight to simulate impact loading.

____ 8. The Bend Test is a static test which is primarily used to check welds. These bend tests are performed on weld qualification test pieces to reveal any defects that may be caused by the welding procedure and to provide a measure of joint ductility.

____ 9. RT_{NDT} is the Reference Temperature for Nil Ductility and it is measured by two tests, the Charpy

V-notch Test and the Dropweight Test. The data from these two tests is correlated to obtain the RT_{NDT} value. This temperature is used as a reference temperature for obtaining the heatup and cooldown curves for the reactor pressure vessel.

____ 10. The shift in RT_{NDT} is due to mostly to gamma ray irradiation effects on the pressure vessel steel. It is not unusual for the ΔRT_{NDT} value to be about 250°F for a PWR Vessel.

____ 11. Both heatup and cooldown stresses are comprised of components of pressure stress, thermal stress and embrittlement stress.

____ 12. The 1/4 thickness and 3/4 thickness positions of the reactor vessel represent positions at which the RT_{NDT} value is more conservative. The crystalline lattice structure within the vessel inherently has a somewhat higher RT_{NDT} value than at the surface of the vessel wall. Hence, for a pressure vessel heatup, the 3/4T position is considered most limiting and for cooldowns, the 1/4T position is considered most limiting.

____ 13. The final nondestructive test method is a Hydrostatic Test. This test is a pressurization of the completed reactor vessel at 6.25 times the design pressure. It is performed to confirm the adequacy of the reactor vessel and to verify the results of all the other nondestructive tests performed on the vessel. The hydrostatic test is always run at a temperature above the measured RT_{NDT} value for the reactor pressure vessel.

____ 14. Materials are certified via a Certified Material Test Report which identifies the specification, grade, class, condition, chemistry results, mechanical test results, heat treatment, and NDE of weld repairs.

____ 15. Materials are marked by the material manufacturer to identify specification number, grade, and heat or lot number. The Fabricator maintains this identification throughout manufacture.

____ 16. Weld repair of materials is controlled by NDE verification of removal of flaw, qualified weld repair procedure and welder, and NDE of completed repair by qualified persons.

____ 17. Fabrication processing identifies all necessary steps for fabrication, inspection and test; identifies correct sequence for performing these steps; identifies detailed procedures applicable to these steps; and permits application of Purchaser hold points.

____ 18. The reactor vessel hydrostatic test confirms the integrity of the vessel and verifies the results of all prior NDE.

____ 19. Reactor vessel certification by the fabricator is accomplished via Data Report Form N-1 which identifies pertinent design, material, fabrication, and test information.

____ 20. RT_{NDT} for the reactor vessel is monitored monthly in the plant to ensure that certified material operating procedures may be followed.

The following answer key is for the true/false questions asked in these exercises.

1. T
2. F
3. T
4. T
5. F
6. T
7. F
8. T
9. T
10. F
11. T
12. T
13. F
14. T
15. T
16. T
17. T
18. T
19. T
20. F

MATERIALS

None.

PROCEDURES

The following procedures refer to Exercises #1 and 2 presented in this module.

1. Assign the students/trainees to tour the heating boiler for your facility or one which is readily accessible. Have the students/trainees obtain the inspection, code requirements for that vessel in the heating system.
2. Have the students/trainees visit an electrical power station (either nuclear or fossil) in your area. Have the students/trainees obtain the code requirements for the pressure vessel used at the plant.
3. Have the students/trainees visit an architectural engineering (AE) firm in your locality. Have the students/trainees discuss the role of the AE in pressure vessel installation and inspection. Have the students/trainees examine the ASME Boiler and Pressure Code Book in the AE office, and write a report about the trip.
4. If possible, visit a nuclear plant site where a reactor vessel is being erected. Review the code installation requirements prior to your trip. While at the plant, take notes on the installation procedure and discuss the special precautions required during the installation.

5. Once again, if possible return to the nuclear station when final inspection and acceptance have taken place and review the final acceptance perocedure with QA personnel on site.

DATA TABLE

None.

REFERENCE MATERIALS

ASME, Section III, ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, 1978

GPO, Title 10 of the Code of Federal Regulations Part 50, Appendix G, Fracture Toughness Requirements for Reactor Pressure Vessels, U.S. Government Printing Office, 1978

NBBI, National Board Inspection Code, A Manual for Boiler and Pressure Vessel Inspectors, Pinsky Publishing & Printing Co., Fourteenth Edition, 1977

ASME, Section II, ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, 1978

TEST

1. State the primary reason for applying stringent testing and quality control requirements on the design, fabrication, and installation of reactor vessels.

2. The 3/4T location is typically limiting with respect to stresses during heatup because:
   a. Flaws are assumed to be present at 3/4T.
   b. Pressure stresses are tensile and temperature stresses are compressive at 3/4T.
   c. Pressure and temperature stresses are compressive at 3/4T.
   d. Pressure and temperature stresses are tensile at 3/4T.
3. The 1/4T location is typically limiting with respect to stresses during cooldown because:
   a. Flaws are assumed to be present at 1/4T.
   b. Pressure stresses are tensile and temperature stresses are compressive at 1/4T.
   c. Pressure and temperature stresses are compressive at 1/4T.
   d. Pressure and temperature stresses are tensile at 1/4T.
4. The stresses at 1/4T become the limiting factor on operation because:
   a. Flaws are assumed to be present at 1/4T.
   b. Neutron embrittlement is greatest at 1/4T.
   c. Radiation increases tensile strength at 1/4T.
   d. Heatup stresses are greatest at 1/4T.

5. The primary failure modes of concern with reactor vessels are:
    a. Elastic deformation and stress corrosion
    b. Brittle fracture and elastic deformation
    c. Plastic deformation and brittle fracture
    d. Fatigue and stress corrosion.
6. Briefly describe elasticity of metals.

7. Briefly describe the effect on a metal when stress is applied (a) slightly above the yield strength and (b) slightly above the ultimate strength.

8. Briefly describe the effect on the relationship of yield strength and ultimate strength as temperature is reduced.

9. Define nil ductility temperature.

10. Name three conditions which are favorable for brittle fracture to occur.

11. Describe the effect on RT_{NDT} caused by neutron irradiation of the reactor vessel.

12. Describe the basis for establishing heatup and cooldown limits for the operation of a reactor vessel.

13. Name two types of documents used as procurement documents for the purchase of reactor vessels.

14. State the purpose of the following inspections and tests of materials:
    a. chemistry analysis

    b. tensile test

    c. drop weight test

    d. Charpy V-notch test

    e. volumetric nondestructive examination

15. Calculate RT_{NDT} given that T_{NDT} = 20°F; C_V at 75°F failed; D_V at 80°F failed; C_V at 85°F failed; C_V at 90°F passed.

16. Briefly describe the controls applied to weld repair of material flaws.

17. Describe certification of material by a material manufacturer.

18. Describe marking of materials.

19. State four purposes of fabrication processing.

20. Describe typical fabrication controls by indicating the control applicable to each of the following:
    a. material identity

    b. drawing requirements on dimensions and form

    c. welding

    d. nondestructive examination

21. State the purpose of the reactor vessel hydrostatic test and briefly describe conduct of the test.

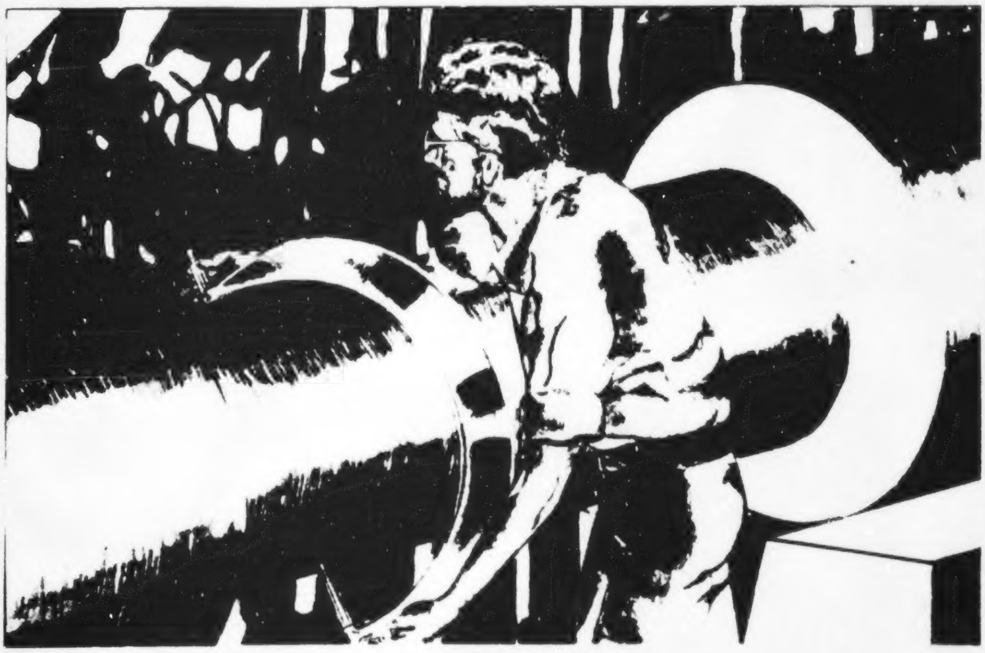
22. Describe how the fabricator certifies each reactor vessel.

23. Why are owner's inspections mostly performed at source of manufacture of the reactor vessel?

NUCLEAR TECHNOLOGY

MODULE 30-8

ROTATING EQUIPMENT INSPECTION



COURSE 30 MECHANICAL INSPECTION

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
4800 LAKEWOOD DRIVE WACO, TEXAS

COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

MODULE 30-1	Pump Inspection
MODULE 30-2	Pump Functional Testing
MODULE 30-3	Valve Inspection
MODULE 30-4	Piping Inspection
MODULE 30-5	Sufrace Cleaning Inspection
MODULE 30-6	Protective Coating Inspection
MODULE 30-7	Pressure Vessel Inspection
⇨ MODULE 30-8	Rotating Equipment Inspection

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INTRODUCTION

The Nuclear QA/QC Technician performs verification inspections associated with installation and test of rotating equipment. These inspections involve review of documentation, monitoring installation activities, and inspecting critical features. Some inspections and tests of rotating equipment require highly specialized skills. These inspections and tests require the use of personnel with specialization in electrical work.

Rotating equipment in nuclear power plants use electrical motors, diesel engines, or steam turbines as prime movers. Loads for these prime movers include valves, pumps, fans, blowers, AC generators, and DC generators. Any of these loads may be very small or quite large. Largest of all are the main power generators which use the steam from the reactor to generate electrical power.

This module describes mechanical inspections and electrical tests which are typically performed at installation of rotating equipment. Many of these inspections and tests are periodically repeated at intervals of plant operation to verify the continued operability of rotating equipment or to indicate the need for corrective maintenance.

MODULE PREREQUISITES

There are no prerequisites for this module.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. State the purpose of preinstallation and installation inspections.
2. Briefly describe typical preinstallation and installation inspections for rotating equipment.
3. State two reasons why shaft alignment is important and briefly describe two methods of inspecting shaft alignment.
4. Briefly describe the Langmuir theory of lubrication.
5 Briefly describe the operation of given lubrication systems including attached forced feed, external forced feed, gravity feed, self-oiling, grease cup and grease fitting.
6. Define the following terms with respect to lubricating oils:
   a. viscosity
   b. flash point
   c. fire point
   d. auto-ignition point
7. State the purpose of turnover tests of oil lubrication systems by the installation contractor and name four examples of items checked by these tests.
8. Name three examples of items checked with respect to oil lubrication systems during equipment load tests.
9. State the purpose and briefly describe the performance of:
   a. continuity tests
   b. insulation
   c. resistance tests
   d. high potential dielectric tests
   e. starting and run current tests,
   f. vibration tests
   g. generator loading tests

h. automatic features actuation tests.

10. Name three components of current which are encountered during insulation resistance tests and describe the effect of each component on measured insulation resistance.

11. Describe the effects on insulation resistance by surface condition, moisture, temperature, magnitude of test potential, duration of application of test potential, and residual charge.

MECHANICAL INSPECTIONS AT INSTALLATION

Basic Types of Installation

Rotating equipment are received at the power plant site as an integral assembly of prime mover and load or as separate components of prime mover and loads. An example of an integral assembly is the 15KW motor-generator set illustrated in Figure 30-8-1. This equipment is supplied as a "package set" with the motor, generator, and flywheel mounted to a base plate by the manufacturer. Shaft coupling, alignment, and balancing have been performed by the manufacturer.

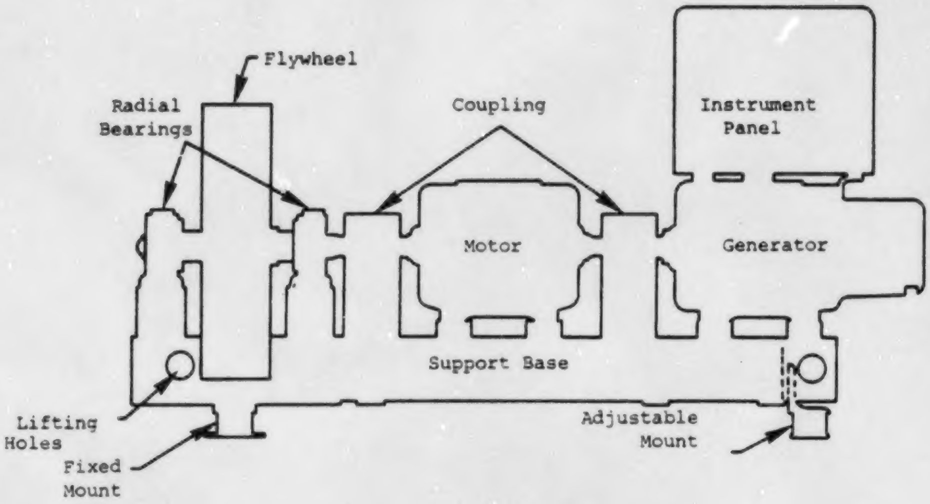

Flywheel
Radial Bearings
Coupling
Instrument Panel
Motor
Generator
Support Base
Lifting Holes
Fixed Mount
Adjustable Mount

Figure 30-8-1. Integral 15KW Motor-Generator Assembly

Many prime movers are received at the power plant site separate from their loads. For each of these, the manufacturer has balanced the rotor and completely assembled the unit. At the installation site, the unit is mounted to its foundational supports and coupled to its load.

Preinstallation Inspections

As construction of a nuclear power plant procedes, components are frequently arriving. These components are receipt inspected and, unless promptly needed for installation, are placed into storage at the site. As construction activities require components for installation, components are withdrawn from stores and moved to the installation area. Preinstallation inspections verify readiness for installation in terms of materials, procedures and drawings. These inspections consist primarily of visual inspections which verify (1) identification, (2) availability of processes and procedures, (3) physical condition of the component and (4) physical condition of the installation site.

Identification of rotating equipment is provided by its nameplate and receipt inspection acceptance tags attached to the equipment. Nameplate data for electrical motors are illustrative; those data include:

- manufacturer
- type of motor
- horsepower output
- speed in revolutions per minute at rated horsepower
- number of phases
- rated operating frequency in hertz
- rated operating voltage in volts or kilovolts
- current at rated voltage and rated horsepower in amperes
- temperature rise above 40°C at rated load in °C
- classification number
- manufacturer's style or model number
- manufacturer's serial number.

Nameplates for other equipment provide similar data which characterizes the equipment. Identification inspection compares nameplate data with the requirements of the installation procedures and drawings to verify that the correct component is selected for installation. Such inspections give particular attention to the type, style, power rating, classification, and speed in order to verify use of the correct component.

Installation activities are performed in accordance with written instructions which are collectively termed job package. The job package contains or references necessary procedures, drawings, instructions, check lists, equipment and fixtures for each segment of installation. The preinstallation inspection of processes and procedures verifies the availability of a complete job package and compliance with prerequisites specified by the job package. For installation of rotating equipment, this portion of preinstallation inspection typically verifies the following:

- approved procedures and installation drawings are available
- installation preparations are complete such as removal of packaging, cleaning, conditioning, and preliminary positioning
- necessary jigs, fixtures, and handling equipment are available

Preinstallation inspection of the physical condition of rotating equipment verifies that the quality of the equipment has been maintained through the operations which relocated the equipment to the specific installation area. Equipment is visually examined for damage, cleanliness, lubrication, and completeness of accessory hardware. In addition, this inspection verifies that any previously reported nonconformance has been corrected.

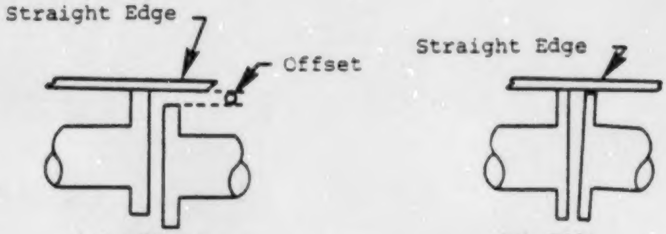
Preinstallation inspection of the site condition visually examines the specific installation area. This examination verifies cleanliness of the immediate area, protection from possible adverse effects from adjacent construction activities, protection from inclement weather, and installation of specified supports and mounts.

Installation Inspections

Installation inspections verify completion of installation work in compliance with the procedures and drawings which comprize the job package. These inspections are primarily comprized of leveling, alignment, completeness of installation and freedom of rotation.

Requirements for leveling are specified by the installation drawing and associated installation procedure. As size of rotating equipment increases, the accuracy of leveling typically becomes more demanding. Dependent on accuracy requirements. leveling of rotating equipment is inspected by precision level, optical telescope, or laser beam.

Alignment of rotor shafts from the prime mover to the load is necessary to prevent vibration and bearing overloads. Where alignment requirements have a tolerance of several thousandths of an inch, straight edges and feeler gages are used for alignment inspection as illustrated in Figure 30-8-2. With the straight edge placed against one hub, the gap between the straight edge and the other hub indicates the extent of misalignment.



(a) Offset

(b) Tilt

Figure 30-8-2. Alignment Inspection With Straight Edge

A more precise inspection of alignment is possible with dial indicators as illustrated in Figure 30-8-3. The reverse indicator method is normally used. First, the indicator is mounted on the power hub such that its axis of revolution is the same as the power hub. Rotation of the dial indicator indicates deviations in the surface of revolution of the load hub. Then the dial indicator is centered on the load hub and readings are taken on the power hub.

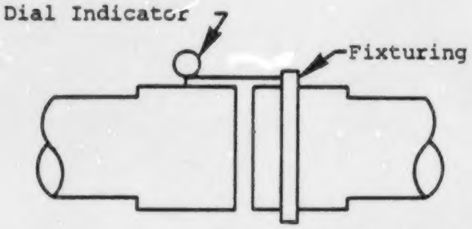


Figure 30-8-3. Alignment Inspection With Dial Indicator

Visual inspections are performed to verify completeness of installation. These inspections may also include witnessing of torquing of threaded fasteners. Typically, visual inspection verifies that the following have been installed or connected as specified by the job package:

- power cables between motors and switch gear
- power cables between generator and output breaker
- external excitation cables
- instrumentation lines
- control circuitry, including relays, switches, stops
- lubrication lines
- cooling lines
- steam lines to turbines
- fuel oil lines to diesel engines

Upon completion of installation, freedom of movement of the rotors of rotating equipment is checked. This check is made by first visually inspecting the equipment for freedom from foreign objects. Then, the rotor is manually turned and observed for binding or rubbing. Upon satisfactory completion of this check, the equipment is released for preoperational testing.

LUBRICATION

Purpose and Theory

The purpose of a lubrication systems as applied to rotating equipment is to reduce the friction between moving parts by replacing solid friction with fluid friction. This reduction in friction produces two desired effects: (1) the quantity of energy required to perform the mechanical action (rotation) is reduced and (2) the amount of energy that is dissipated as heat is reduced.

Fluid lubrication provides physical separation of surfaces such that metal-to-metal contact is avoided. This is possible due to two important components of fluid friction: (1) cohesion between particles of the lubricating fluid and (2) adhesion of the fluid particles to the object which is tending to move the fluid. As long as the fluid flow remains intact, the only friction present is fluid friction, which is desired.

The Langmuir Theory of lubrication explains that, there are three or more layers of films of lubricant existing between two lubricated bearing surfaces. This is illustrated in Figure 30-8-4. As illustrated, the two outer most layers (1 and 5) are boundary films with one adherent to the stationary member and one adherent to the moving member. The two boundary layers are separated by one or more fluid films. When the rotating journal begins its motion, the position of the journal relative to the bearing lining is such that a wedge of lubricants is formed. The oil layers between the boundary layers continuously provides through cohesion, a physical separation between the two metal surfaces thus providing the desired fluid friction.

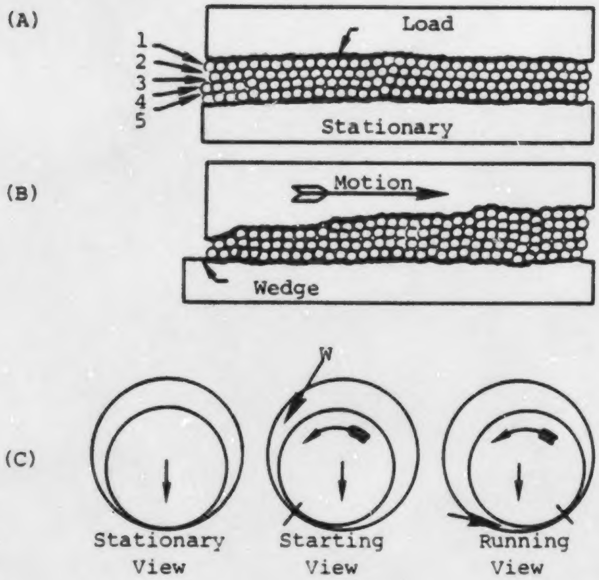


Figure 30-8-4. Oil film lubrication, (A) Stationary position, showing several oil films; (B) surface set in motion, showing principle of oil wedge; (C) principle of (A) and (B) shown in a journal bearing.

Characteristics of Lubricants

There are two basic types of lubricants used in nuclear power plants; these are oils and greases. Oils are typically used by turbines, internal combustion engines, combustion turbines, large motors and reduction gears. Grease is employed where the retention of lube oil at the bearing surface may be difficult, i.e. valve reach rods/extensions, horizontal small motors, or gear chains.

The following attributes of oils are of concern in selecting the specific oil to be used. Component and system design specifications state specific values for these attributes. Installation inspection verifies that oils having specified attributes are used.

- viscosity - its tendency to resist flow or change of shape

- pour point - lowest temperature at which the oil will barely flow from a container
- flash point - point corresponding to the temperature at which enough vapor given off to flash when a flame or spark is present
- fire point - point corresponding to the temperature at which the oil will continue to burn when ignited
- auto-ignition point - corresponding temperature at which the flamable vapors given off from the oil ignite without the application of a spark or flame
- neutralization number - the measure of the acid content in terms of milligrams of potassium hydroxide (KOH) required to neutralize one gram of the oil
- demulsibility - the ability to separate cleanly from any water present
- precipitation number - measure of the amount of solids or asphalts or carbon residue contained in the oil.

Greases are classified by application within the plant. These classifications are:

- Group I - General purpose, operating temperature range - 40 to 250°F
- Group II - High temperature, operating temperature range - 0 to 300°F
- Group III - Medium temperature, operating temperature range - 32 to 300°F
- Group IV - low temperature, operating temperature range - 67 to 225°F
- Group V - extreme high temperature, short period operating temperature up to 450°F

Oil Lubrication Systems

The three basic types of oil lubrication systems used within nuclear power plants are (1) Force Feed,

(2) Gravity feed and (3) self oiling system. The first, force feed, is subdivided into attached types as in the case of the oil system of a diesel engine and the external type as in the case of a large turbine generator complex.

The attached force feed oil lubrication system, as represented by the diesel oil system illustrated in Figure 30-8-5, depends upon the diesel engine as the prime mover for the attached oil circulating pump. This pump is coupled to the crankshaft through a series of gears and provides oil flow only when the engine is operating. In addition to strainer and filters, the lubrication system has an oil cooler and relief protection. The typical loads or items to be lubricated by this system are:

- main crankshaft bearing
- main thrust bearing
- running gear
- cam shaft bearings
- turbocharger bearing
- front gear train.

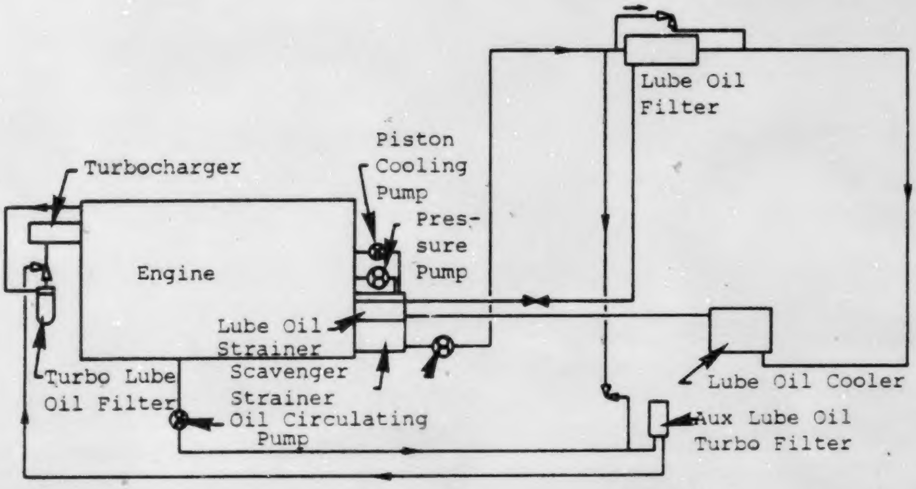

Lube Oil Filter
Piston Cooling Pump
Turbocharger
Pressure Pump
Engine
Lube Oil Strainer
Scavenger Strainer
Turbo Lube Oil Filter
Oil Circulating Pump
Lube Oil Cooler
Aux Lube Oil Turbo Filter

Figure 30-8-5. Attached Lube Oil System

The external forced feed oil lubrication system differs from the attached system in that the components being lubricated depend upon an externally powered force feed oil system which typically is called an auxiliary system. The external oil lubrication system is illustrated in Figure 30-8-6.

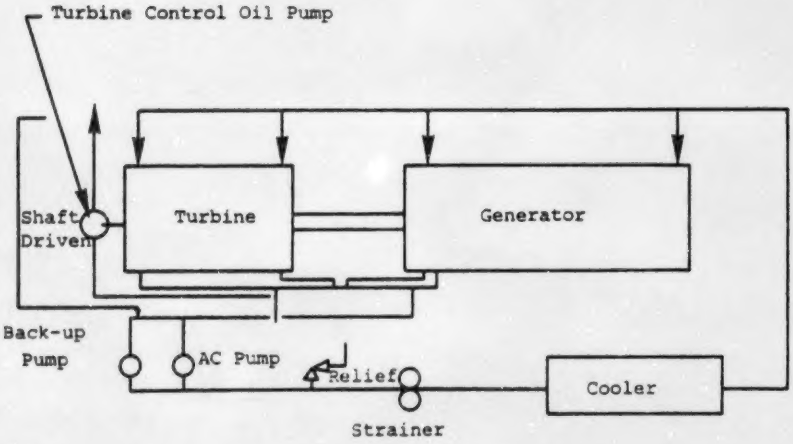


Figure 30-8-6. External Lube Oil System

As illustrated by figure 30-8-6, an AC motor driven lube oil pump supplies the oil to the bearings of the turbine and the generator. This AC pump has an emergency back-up pump which is powered from an independent power source thus providing protection from a loss of normal power. A shaft driven oil pump is used in this system, but not for lubrication purposes. Instead, it supplies the control oil for the turbine control system. Like the previous system there are reliefs, strainers and coolers.

Gravity feed applications as illustrated by figure 30-8-7, are more simple and are basically either, drip feed,

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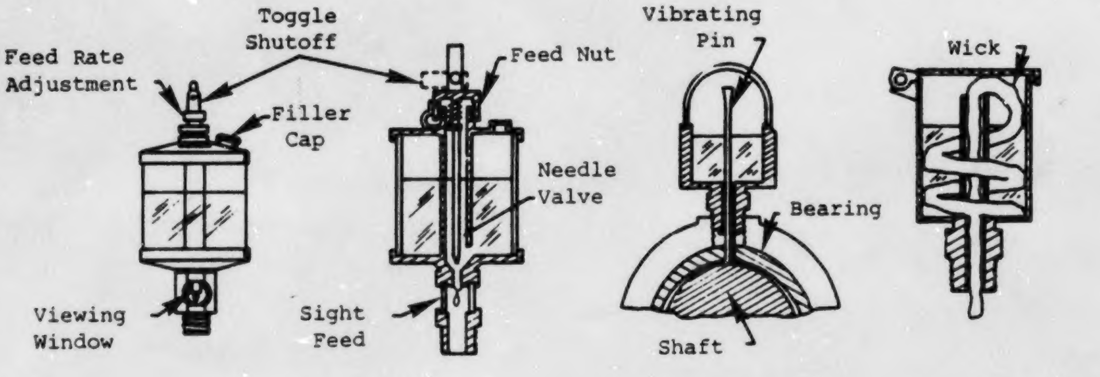
vibrating pin or wick feed. In each of these cases the lubrication is localized such that each device usually services only one component, e.g., one bearing. These devices are under a scheduled service routine to ensure that the reservoir has sufficient oil for the intended lubrication period. These units find limited application in power plants.


Toggle Shutoff
Feed Rate Adjustment
Filler Cap
Feed Nut
Needle Valve
Viewing Window
Sight Feed
Vibrating Pin
Bearing
Shaft
Wick

(a) Drip Feed (b) Vibrating Pin (c) Wick Feed

Figure 30-8-7. Gravity Feed Lubrication Units

"Self-oiling" lubrication systems are illustrated in Figure 30-8-8.

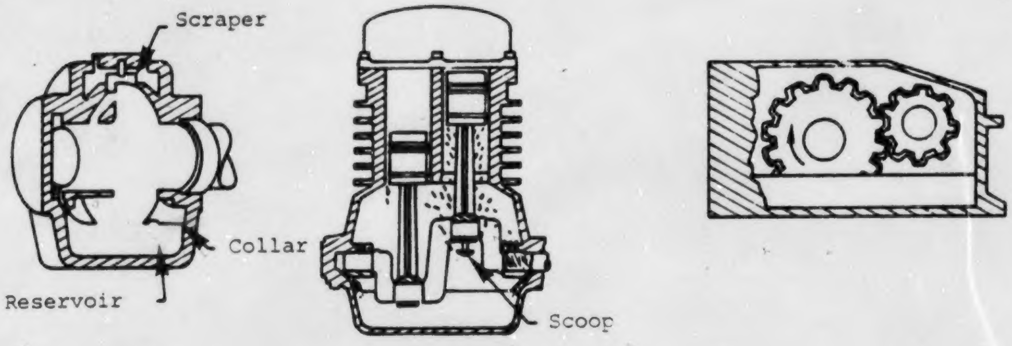

Scraper
Collar
Reservoir
Scoop

Figure 30-8-8. Self Oiling Lubrication Systems

In each of the examples shown in Figure 30-8-8, a transfer device (collar, scoop or gear teeth) is used to transfer the oil from the sump to the area where fluid friction is desired. This method is very simple as in the case of the gravity feed system but enjoys wider application in the power plant due to its greater reliability. While the sumps provide a return for the excess oil, there is still a need to provide scheduled surveillance to ensure quantity and quality of the oil.

Grease Lubrication

As described earlier, grease lubrication is used in locations where the retention of lube oil at the bearing surface is difficult. The two basic types of grease application widely used in the power plant are grease cups and pressure fittings.

The grease cup is used to force grease into a grease cavity be means of a screw arrangement. The cavity is directly open to the cup and usually minimum force is required to introduce new grease to the component. Figure 30-8-9 illustrates a grease cup. A drawback associated with this form of lubrication is the tendency to overgrease. Grease cups may be used on small motors, valve stems and sometimes on pump packing glands.

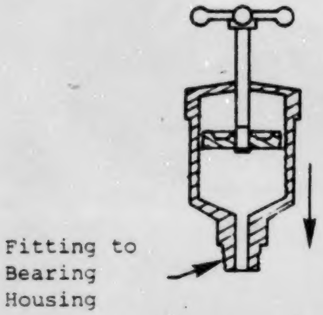


Figure 30-8-9. Grease Cup

Pressure fittings, often termed "ZIRK", are used primarily for small motors, valve stems, and pump packing glands. As illustrated in Figure 30-8-10, grease is forced by a grease gun through the fitting ball valve to the bearing. The ball valve is spring loaded to prevent reverse flow. Usually the old grease is forced out of the bearing as the new grease is forced in. The major advantage of the grease fitting over the grease cup is the ability of the grease gun to apply fresh grease which has not been subjected to environment prior to use.

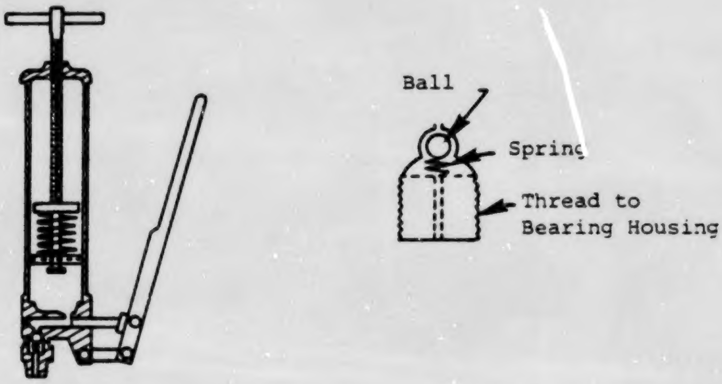


Figure 30-8-10. Grease Gun and Fitting

Functional Testing of Lubrication Systems

Lubrication systems are initially tested by the installation contractor prior to turn over of the component/ system to the owner/operator. At this time a functional test of the lubrication system is conducted under no load conditions if at all possible. In the case of attached force feed systems (e.g. diesel) a "no load" test is impossible. In cases like this, the initial test is under as minimal a load as possible. However for the external forced feed oil system, a no load test is possible.

Regardless of the load, the initial turnover tests verify that the lubricating system functions in terms of oil flow and pressure.

Turnover tests without applying a load condition actually indicate satisfactory operation "so far". This is acceptable at this point because the primary concern is with individual lubrication flows to the respective components. Once this basic fact is established, the owner/operator performs more detailed load acceptance tests. Additional items which are checked during turnover tests are:

- standby features
- pump vibration
- strainer cleanliness
- foaming
- tightness of joints
- level alarms
- sight flows
- temperature detector operability
- relief valve operation
- pressure regulating valve operability.

Load acceptance tests are typically accomplished in conjunction with component load testing during cold and hot functional testing. Such load tests are described later in this module. During these tests, additional characteristics checked with respect to lubrication are:

- lube oil temperature rise across bearing
- return oil flows
- lube oil cooler operation
- oil pressure regulator operation under elevated temperatures
- bearing temperature.

While the preceding tests directly apply to "lubrication system", the same principles are applicable to the gravity feed arrangements and the grease cups. Checks on these systems include:

- oil level in reservoirs.
- smooth and quiet operation of the equipment.
- cool bearing operation (e.g., not hot to the touch)
- oil visible in viewing windows.

In summary, lubrication is essential to the operation of rotating equipment and regardless of the size of the component, the same questions need to be answered by the inspector:

- Does the unit have lubrication?
- Is it the correct type as called for by design?
- Does the "lubrication system" lubricate and provide fluid friction for the rotating components as evidenced by temperatures, vibration, and oil flows and pressures?

ELECTRICAL TESTS

Types of Tests

The extent of testing of rotating equipment is specified by engineering based on regulatory requirements and importance of the equipment to the safe operation of the power plants. Tests are time-sequenced to permit necessary interfacing with other plant systems. Typical tests in their order of performance are as follows:

- continuity tests
- insulation resistance test
- high potential dielectric test
- starting and run current tests
- vibration tests
- generator loading tests
- automatic features actuation tests.

Continuity Tests

Continuity tests verify that power control and instrumentation conductors are connected to correct terminals and have electrical continuity. These tests check continuity of conductors from the equipment to the first breaker, switch, or relay in the cable run. The remainder of power distribution and circuitry are tested separately. Figure 30-8-11 illustrates the continuity test.

Referring to Figure 30-8-11, the phase C conductor is tested individually by lifting the connection at one end. This removes circuit paths through the motor which could disguise improper wiring. If phase C at the motor is connected to phase C at the switch gear, the voltmeter reads applied voltage provided no opens or shorts exist on conductor C. Otherwise, the voltmeter reads zero. Phase C is then reconnected, and the other phases are individually tested in like manner.

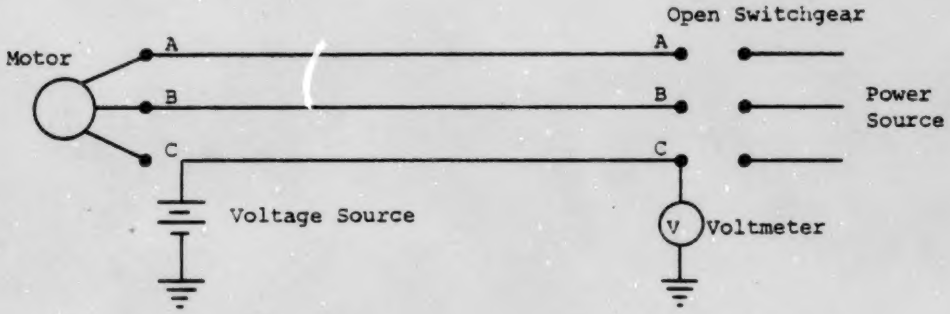


Figure 30-8-11. Continuity Testing

Insulation Resistance

Insulation resistance is the term used to describe the quotient of applied direct electrical potential divided by current caused by that potential at some given time after application of the potential. The potential is applied between the conductor and ground. Therefore, the current

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caused by the potential must flow through the insulation which surrounds the conductor. The relationship is expressed by a variation of Ohm's law:

$$R = \frac{E}{I} \qquad \text{Equation 30-8-1}$$

where:

R = insulation resistance
E = potential applied
I = current measured

The fundamental concept of insulation resistance is illustrated in Figure 30-8-12. As illustrated, insulation resistance is inversely proportional to the cummulative currents in all possible leakage paths.

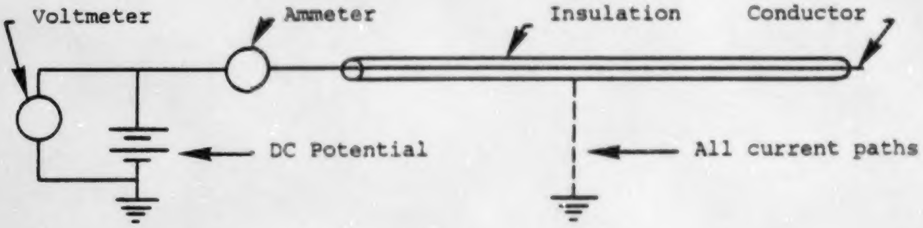


Figure 30-8-12. Insulation Resistance

Referring to Figure 30-8-12, the current at the instant of application of the potential is comprized of three components. First, capacitance charging current is initially of relatively high value. This current decays rapidly and is of short duration. Due to the rapid decay, capacitance charging current does not affect the measurement of insulation resistance. Second, absorption current is initially of a comparatively high value and slowly decays to essentially zero. This current is within the volume of insulation and affects measurement of insulation resistance for several minutes. Third, conduction current is essentially constant if all other conditions are constant. Conduction current is the surface leakage current to ground.

The insulation resistance of windings withing rotating equipment is a function of the type and assembly of insulating material. In general, insulation resistance varies directly with thickness of insulation and inversely with conductor surface area. Potential paths for conduction current includes from phase to phase and from phase to ground. Insulation resistance is affected by (1) surface condition, (2) moisture, (3) temperature, (4) magnitude of test potential, and (6) residual charge in the winding.

Foreign matter, such as carbon dust, or insulation surfaces tend to lower insulation resistance. As moisture content of such foreign matter increases, the insulation resistance generally decreases substantially. Cleaning and drying insulation surfaces normally brings insulation resistance up to its normal value.

Regardless of cleanliness of insulation surfaces, moisture films on insulation surfaces tends to lower insulation resistance. Many insulation materials absorb moisture to some extent and are very susceptible to decreases in insulation resistance with increasing moisture content. This adverse effect can be avoided by keeping the windings above dew point temperature when the equipment is idle.

Insulation resistance of most materials varies inversely with temperature. Generally, measured insulation resistance doubles for each 10°C reduction in temperature. Measured insulation resistance is corrected to the established standard temperature of 40°C by the formula:

$R_c = K_t \times R_t$ Formula 30-8-2

where:

R_c = insulation resistance corrected to 40°C in megohms

K_t = insulation resistance temperature coefficient at temperature t

R_t = measured insulation resistance at temperature t in megohms.

The insulation resistance temperature coefficient may be determined by measuring insulation resistance at several temperatures, all above the dew point, and plotting the results. Using the plot, the temperature coefficient at any temperature can be calculated by solving Formula 30-8-2 for K_t. An approximate value of K_t is given in Figure 30-8-13 which is based on a doubling of insulation resistance for each 10°C reduction in temperature.

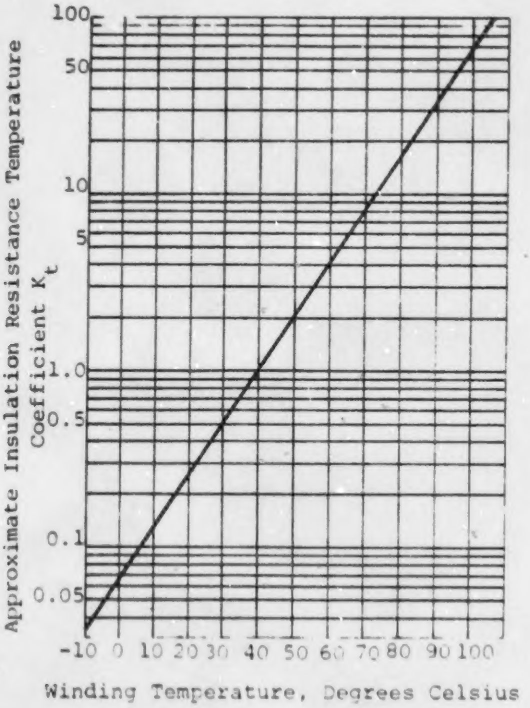


Figure 30-8-13. Approximate Insulation Resistance Temperature Coefficient with Temperature

The test potential used for measuring insulation resistance must be equal to or less than the peak voltage rating for the winding in its basic condition. Variation of test potential below voltage rating yields essentially constant measurements of insulation resistance provided the insulation is clean and dry. If resistance decreases substantially with increasing test potential below voltage rating, the insulation probably contains imperfections or cracks aggravated by foreign matter or moisture. Test potentials above voltage rating overstresses the insulation. Excessive test potentials yield a decreasing resistance reading as test potential increases.

As the duration of application of test potential increases, the measured value of insulation resistance increases up to a fairly stable value. This effect is primarily caused by absorption current. The increase in measured resistance initially increases rapidly from the time of application of test potential but then gradually approaches a stable value. A fairly steady value is typically reached in ten to fifteen minutes.

Foreign matter and moisture not only lowers the measured value of insulation resistance but also lowers the rate of rise of resistance with duration of test potential. Therefore, the rate of rise of insulation resistance with duration of test potential is useful in appraising the cleanliness and dryness of windings. To provide such appraisal, the polarization index may be used for acceptance of insulation resistance. Polarization index is indicative of the rate of rise in insulation resistance with duration of test potential and is calculated by:

$$PI = \frac{R_{10}}{R_1}$$ Formula 30-8-3

where:

PI = polarization index

R_{10} = insulation resistance at 10 minutes after application of test potential

R_1 = insulation resistance at 1 minute after application of test potential

Residual charge in the windings causes erroneous readings of insulation resistance. Prior to connecting the measurement equipment, residual charge is removed by grounding the winding to be measured. Also, after measuring insulation resistance, the winding is again grounded to remove residual charge caused by application of the test potential. Such grounding dissapates capacitive and absorption current. Grounding time is four times the charge time.

Insulation Resistance Tests

All measuring equipment for insulation resistance work on the concept illustrated in Figure 30-8-12. Variables among types of equipment include test potential and power source. Basically measuring equipment have test potentials in the range of 500V to 5000V and are available in the following types:

- direct indicating ohmmeter with hand or power driven generator.
- direct indicating ohmmeter with self contained battery
- direct indicating ohmmeter with self contained rectifier and external AC power source.
- resistance bridge with self contained galvanometer and batteries.

In addition to equipment designed for measuring insulation resistance, the test set-up illustrated in Figure 30-8-12 can be used. That is, an appropriate power source, a voltmeter, and a microammeter can be individually connected as illustrated. In such cases, insulation resistance is calculated by Formula 30-8-1.

Regardless of the instrument used, certain prerequisites are observed prior to measuring insulation resistance. These prerequisites are verification that:

- winding temperature is above dew point
- residual charge is dissapated
- test potential is equal to or less than peak voltage rating of the winding.

Insulation resistance tests of windings of three phase rotating equipment are made with the neutral end of each phase disconnected when possible. In this manner, phase-to-phase insulation resistance as well as phase-to-ground insulation resistance is tested. In addition, external circuits which affect winding insulation resistance measurements are disconnected when possible. This includes disconnecting power leads, brush rigging, switches, capacitors, and lightning arrestors.

Acceptance criteria for insulation resistance is specified by engineering as either minimum resistance or minimum polarization index. Therefore, the insulation resistance test verifies the quality of insulation in terms of actual resistance or polarization index.

Minimum resistance applies to the measured value at one minute after application of test potential and corrected to 40°C. Minimum polarization index applies to the ratio of the ten minute reading to the one minute reading. Resistance readings are always corrected to 40°C. Temperature effect on polarization index is small if winding temperature at the ten minute reading is essentially equal to temperature at the one minute reading. However, at high temperatures, the temperature characteristics of the insulation may yield an abnormally low polarization index. Another test at a temperature below 40°C should be made in such cases to better determine the real insulation resistance.

Acceptance criteria in terms of polarization ratio typically requires a minimum ratio of 1.5 or 2.0 depending upon class of insulation. Values as high as 7 may be obtained in measurements. Minimum insulation resistance at the one minute reading is typically based on effective voltage rating of the rotating equipment. The relationship is expressed by:

$R_m = kv + 1$ Formula 30-8-4

where:

R_m = minimum insulation resistance at 40°C of entire machine winding in megohms

kv - rated machine terminal to terminal potential in rms kilovolts

Example:

Problem: Does the insulation resistance reading of 25 megohms measured at 22°C indicate compliance with the specified minimum insulation resistance of 10 megohms?

Given: R_t = 25 megohms, t = 22°C, R_m = 10 megohms

Solution: Determine k_t from Figure 30-8-13.

$k_t = 0.3$

Using Formula 30-8-2, calculate R_c

$$\begin{aligned} R_c &= K_t \times R_t \\ &= 0.3 \times 25 \\ &= 7.5 \text{ megohms} \end{aligned}$$

Because $7.5 < 10$, the insulation resistance fails to meet acceptance criteria.

Example:

Problem: Is winding insulation acceptable if a minimum of 2.0 polarization index is required, the one minute insulation resistance measurement at 60°C is 100 megohms, and the ten minute measurement at 55°C is 380 megohms.

Given: R_{t1} = 100 megohms, t_1 = 60°C, R_{t10} = 380 megohms, t_{10} = 55°C, PI_m = 2.0.

Solution: Obtain temperature coefficients from Figure 30-8-13 and correct the one minute and ten minute readings to 40°C

$$R_{c1} = 4.1 \times 100$$
$$= 410 \text{ megohms}$$

$$R_{c10} = 3 \times 380$$
$$= 1140 \text{ megohms}$$

Calculate polarization index

$$PI = \frac{1140}{380}$$
$$= 3$$

Because 3 > 2, the windings are acceptable

High Potential Dielectric Tests

High potential dielectric tests determine the maximum potential which insulation can withstand without failure. This test is applied only to large AC machines rated at 10,000 kVA or greater and 6000V or higher. The test may be performed by the manufacturer or by the installer or both. Maximum test voltage is as much as 2.5 times the rated voltage of the machine but lower than anticipated breakdown voltage of the insulation.

Insulation is verified to be in good condition prior to performing a high potential test. Typical prerequisites for the test include verification that (1) insulation resistance is greater than the specified minimum, (2) polarization index is greater than the specified minimum, and (3) winding temperature is 40°C or greater. In addition, all auxiliary equipment is disconnected and each phase is independently tested insofar as possible.

Special test equipment is needed for high potential dielectric tests. The high DC voltage is typically provided by a variable autotransformer and rectifier. The line voltage and frequency to the primary of the autotransformer are regulated to avoid variations in test measurements due to line variations. Other loads on the line supply are not changed for the duration of the test. The autotransformer is adjustable in small continuous increments. A kilovoltmeter with several ranges is included. Microammeters have several ranges and electrostatic shielding. Large leads, substantial ground straps and elimination of sharp corners in all connections reduce corona effects. The basic test arrangement is illustrated in Figure 30-8-14.

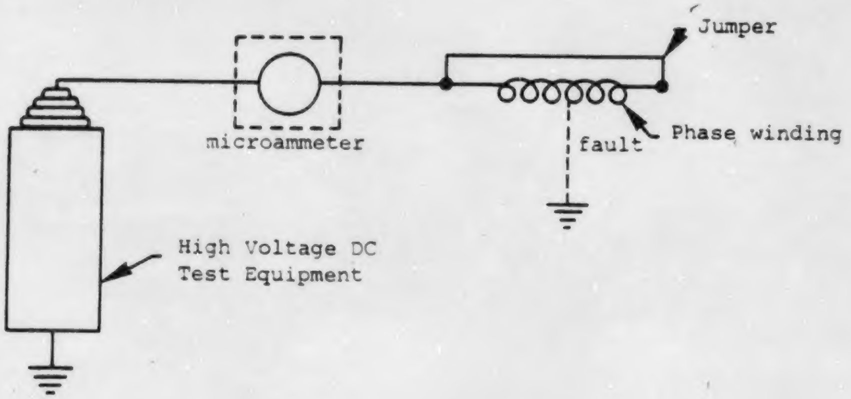


Figure 30-8-14. High Voltage Test Arrangement

High potential dielectric tests may be performed as proof tests or controlled overvoltage tests. The proof test determines if insulation withstands the applied test voltage. The controlled overvoltage test predicts breakdown voltage and provides information for comparison among phases or subsequent tests.

Proof tests are performed by gradually increasing test voltage and observing the current measurement. If current exceeds the specified maximum at any time, test voltage is reduced and the test is terminated until cause of the excess current is determined and corrected. If current does not exceed limits, test voltage is gradually increased to maximum test voltage and held for one minute. If no evidence of distress or failure is observed at the end of one minute, at maximum test voltage, the machine is considered satisfactory and test voltage is slowly reduced. At the conclusion of the test, the winding is grounded for a time at least equal to four times the duration of the test to dissipate residual charge.

Controlled overvoltage tests are performed by timed increments and increasing test voltage while plotting measured current against applied voltage. Initially, approximately one-third of maximum test voltage is applied and held for ten minutes to permit calculation of polarization index. If the polarization index is satisfactory, test voltage is increased at one minute intervals in steps of 3% or less of maximum test voltage. The voltage adjustment is made within the first 10 seconds of the one minute interval and not adjusted again until the next interval. The current is measured at the end of each one minute interval and immediately plotted. The series of voltage increases and current measurements are continued until there is indication of pending failure or maximum test voltage is reached, whichever first occurs.

Indication of pending failure of the insulation is provided whenever there is a marked change in the slope of the plot as illustrated in Figure 30-8-15. Such indication normally occurs at a test voltage at least 5% below estimated breakdown voltage. The breakdown voltage is estimated by extrapolation to the point where the curve is vertical. Test voltage is increased one additional increment if conservatism permits. If pending failure is still indicated by extrapolation of the plot, the test is terminated.

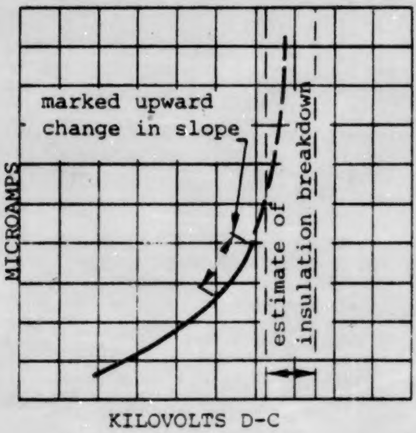


Figure 30-8-15. High Potential Dielectric Test Results

The high potential dielectric test is terminated by slowly reducing test voltage. This avoids rapid field changes which might induce failure. After reducing test voltage, the winding is grounded by a grounding rod with a resistor and then grounded with a grounding rod without a resistor. Then a grounding strap is attached and left in place for about one hour to ensure dissipation of residual charge.

High potential dielectric tests are used to predict when maintenance is necessary. The initial test of new equipment provides data against which subsequent tests are compared. When tests indicate breakdown voltages lower than anticipated, some deterioration in insulation is suspected and maintenance is scheduled.

Starting and Run Current Tests

Starting and run current tests verify acceptable motor performance under load. (It is noted that generator tests are described later in this module.) These tests are conducted as preoperational or cold functional tests and require that load systems and motor lubrication and cooling systems be functional.

Current is typically measured with portable tong meters although chart recorders and permanently installed ammeters may be used. Tong meters operate on a principle illustrated in Figure 30-8-16. The magnetic field around a conductor induces current flow in the magnetic tong. The magnetic field of this secondary current flow is sensed and displayed on a meter. Tong meters are available as ammeters, voltmeters, watt-meters, volt-amp meters, and power factor meters.

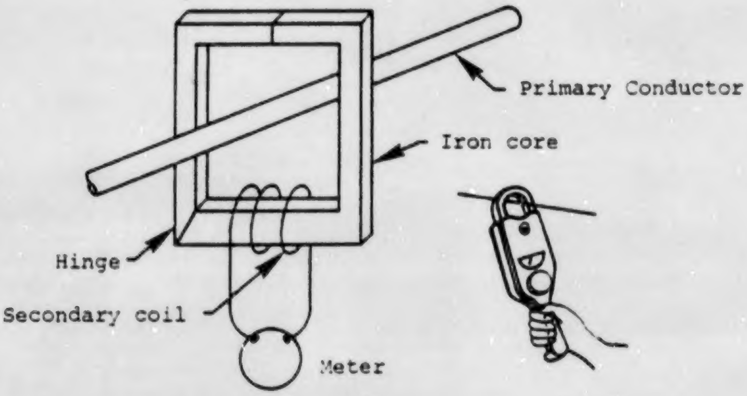


Figure 30-8-16. Tong Meter Operation

Tong meters with special stops are used for measuring starting current. In these, the meter indicator is locked at its maximum reading and does not return to zero until the lock is released. In this manner, peak current which occurs at initial start of the motor is captured and hence, readable.

Starting and run current tests are performed with the motor subjected to the loading conditions which occur in plant operation. If the motor normally starts with load, the test is performed with load. If the motor normally has load applied after being started, the test duplicates these conditions. Starting current is measured under normal starting conditions and run current is measured with the motor fully loaded. The measured values are compared with specified limits to determine acceptance. Limits are specified by system design specification and nameplate.

During run current tests, motor and bearing temperatures are also checked for compliance with limits. This confirms adequate cooling and lubrication of the motor and its bearings.

Vibration Tests

Vibration tests verify that rotating equipment are sufficiently rigid, aligned, and balanced to avoid excessive vibration during operation. These tests are performed for turbines, motors, and generators. The equipment is typically tested in the no-load condition and then tested at various loads up to full load. Vibration may be caused by misalignment, loose mounts, worn bearings, unbalanced rotor, bent or cracked shaft, or excessively pulsating loads.

Basic limits on vibration are typically specified in "mils" where a mil equals 0.001 inch. Several direct reading vibration detectors are available for measuring vibration in mils. One type uses a dial indicator with a plunger through a spring within a weighted case. The inertia of the weighted case causes it to remain relatively stationary when the instrument is placed in contact with a vibrating surface. The vibrations are transmitted by the plunger to the dial indicator such that the indicator reading oscillates between points on the dial. The difference between the maximum points of oscillation equals the peak-to-peak vibration in mils. Another type of instrument has a stylus connected to a mirror such that the tilt of the mirror oscillates proportional to vibration. A point light source directed at the mirror reflects to a frosted scale and appears as a white line. The length of the line indicates peak-to-peak vibration in mils.

Basic vibration tests use portable vibration detectors in contact with bearing and coupling housings to measure vibration. Measurements are typically made at no-load, partial load, and full load conditions. Results are compared directly with specified limits for acceptance.

Continuous vibration monitoring of generator sets is increasingly being used. Continuous monitoring systems use piezoelectric crystals mounted on key surfaces and attendant electronic circuitry for measuring output of the crystals. These systems provide for several measurements. Measurement of amplitude of all frequencies of vibration provides an equivalent reading as the vibration detectors previously described. Total amplitude is typically used to initiate an alarm and equipment shutdown at consecutively higher levels of vibration. This protects the equipment from catastrophic failures when more minor problems are causing an increasing vibration. In addition, many of these systems have electronic circuits which measure frequency and phase components of vibration. This permits vibration analysis vice monitoring. Vibration analysis is used to detect deteriorating conditions and to pinpoint the parts causing the vibration. In this manner, maintenance is scheduled before failure occurs.

Generator Loading Tests

Generator loading tests verify the mechanical and electrical performance of generators under various load conditions. These tests are performed for motor-generators, turbine-generators, and diesel-generators.

Stator winding temperature and bearing temperatures are the principal temperatures of concern for AC generators. Armature temperature is also of primary concern for DC generators. These temperatures are measured by permanently installed detectors or by measuring temperatures of the cooling medium. Thermocouples or resistance temperature detectors provide for temperature detection. Cooling mediums may be air, water, or hydrogen.

Tests are performed by sequential loading of the generator while normal cooling and lubrication methods are functioning. Temperatures are monitored to determine that anticipated cooling of both windings and bearings occurs. Loading continues until rated generator capacity is reached. Full load is continued for a specified "run" time to verify satisfactory cooling and lubricating at continuous duty at full load. Vibration tests may be conducted simultaneously.

At intervals of loading, the electrical performance of the generator is checked. These checks typically determine speed and voltage controls and may also, measure phase balance, and power factor. For AC and DC generators, output voltage is variable with speed and field current. Also output frequency of AC generators is variable with speed. In most applications speed is held constant at the correct rpm and field current is adjusted to maintain voltage. As loading increases, the power transmitted by the prime mover must increase in order to maintain constant speed. Automatic or semi-automatic controls are typically used to adjust power to the prime mover to maintain constant speed and to adjust generator field current to maintain output voltage. The control devices permit manual adjustments by operators as necessary. The proper functioning of the speed and voltage controls as well as the manual adjustments are checked during loading tests.

Automatic Features Actuation Tests

In the event of loss of reactor and off-site power, diesel-generators automatically start and supply emergency power to critical components which provide for safe reactor cooling. Automatic features actuation tests verify that the emergency diesel generators start and supply power to loads as designed whenever actuating conditions occur.

Actuating signals for emergency diesel-generators originate from certain plant parameters and power on essential electrical busses. Plant parameters are typically containment radiation, reactor coolant pressure, and containment pressure. Abnormal values for these parameters are indicative of some type of accident which may require emergency power. Loss of voltage on essential busses is definitely indicative of the need for emergency power. A simplified block diagram of actuating signals is given in Figure 30-8-17.

Referring to Figure 30-8-17, essential bus loads are normally supplied by the main turbine generator or off-site power. The diesel generator is shutdown and its output breaker is open. The plant parameters are normally within design limits and there is no signal from any of the bistables. It is noted that three or four redundant channels which are not shown in Figure 30-8-17 are used for measuring each plant parameter. In order to trigger the bistable, at least two channels for a given parameter must reach the trip point. This precludes actuation by a single, false signal.

High containment radiation, high containment pressure, or low reactor coolant pressure trips their bistable and sends a signal which starts the diesel. This prepares the diesel for supplying power if normal power to the essential bus is also lost. Whenever normal power to the essential bus is lost, the voltage sensor initiates a signal which

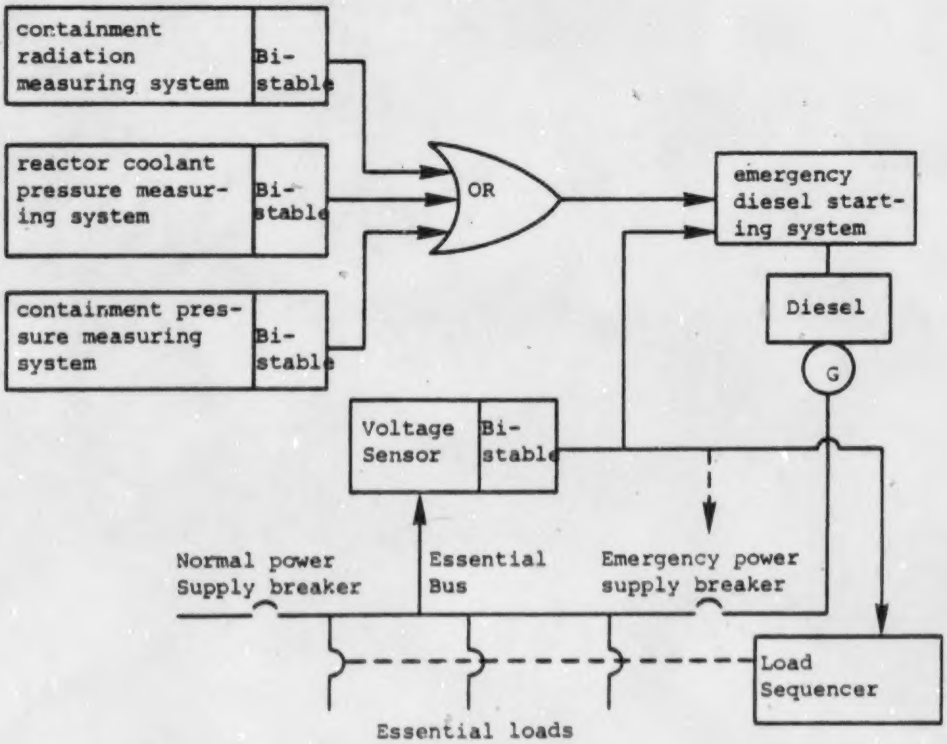

containment radiation measuring system
Bi-stable
reactor coolant pressure measuring system
Bi-stable
containment pressure measuring system
Bi-stable
OR
emergency diesel starting system
Diesel
G
Voltage Sensor
Bi-stable
Normal power Supply breaker
Essential Bus
Emergency power supply breaker
Load Sequencer
Essential loads

Figure 30-8-17. Simplified Block Diagram of Safety Features Actuation of Emergency Diesel Generator

starts the diesel and activates a load sequence. Simultaneously, the normal supply breaker trips open on undervoltage and the voltage sensor closes the diesel-generator output breaker. Therefore, as the diesel is coming up to speed under loss of normal power conditions, its output breaker is closed. Because essential loads may initially overload the diesel-generator, breakers to essential loads are also equipped with undervoltage trips and these breakers open upon loss of normal power. The load sequencer recloses breakers to essential loads at timed intervals of about five seconds each. This permits the diesel-generator to reach operating speed prior to loading and it staggers the starting currents of essential loads. In this manner, power is quickly and safely restored to essential loads such as core spray pumps, safety injection pumps, containment spray pumps, power operated valves in these systems, and reactor instrumentation and control systems.

Tests of safety features actuation of the emergency diesel generator are performed as two separate tests. One simulates plant parameters, confirms bistable trips at specified set points, and verifies diesel starting. The other test opens the normal supply breaker and verifies diesel starting and load sequencing. Test prerequisites establish system lineup of the affected systems such that emergency sprays and injections do not actually occur as a result of the test.

EXERCISES

This check list summarizes the major points of this module. Put a check by each point as you recall it.

____ Preinstallation inspections verify readiness for installation in terms of materials, procedures, and drawings.

____ Preinstallation inspections are primarily visual inspections which verify (1) component identification, (2) availability of processes and procedures, (3) physical condition of the component, and (4) physical condition of the installation area.

____ Installation inspections verify completion of installation work in compliance with the procedures and drawings which comprize the installation job package.

____ Installation inspections are primarily dimensional inspections of leveling and alignment, visual inspections of completeness of installations, and verification of freedom of rotation by manually rotating the equipment.

____ Alignment inspection methods include the straight edge and dial indicator methods.

____ Lubrication according to the Langmuir theory provides fluid friction by the adhesion and cohesion properties of oils which result in layers of oil forming a separating wedge between rotating and stationary member.

____ Important properties of oils include viscosity, flash point, fire point, auto-ignition point, neutralization number, demulsibility, and precipitation number.

____ Types of oil lubricating systems include force feed, gravity feed, and self oiling.

____ Forced feed oil systems include those with oil pumps attached to and driven by the equipment being lubricated and those with separate oil pumps powered by external sources.

____ Gravity feed oil lubrication systems use an oil reservoir which provides oil feed by gravitational flow.

____ Self oiling lubrication systems use an oil sump from which tranfer devices attached to the equipment being lubricated lift oil to the areas to be lubricated.

____ Grease lubrication systems include grease cup and grease fitting. Grease cups contain a reserve of grease which is forced into the part by a threaded plunger or piston. Grease fittings permit application of grease by grease gun.

____ The installation contractor performs turnover tests of oil lubrication systems which verify operability of the system under no load conditions.

____ The owner performs load testing of rotating equipment which also includes verification of functions of the lubricating system under load conditions.

____ Continuity tests verify that conductors are connected to correct terminals and have continuity.

____ Insulation resistance is affected by surface condition, moisture, temperature, magnitude of test potential, duration of application of test potential, and residual charge.

____ Insulation resistance tests either measure insulation resistance at one minute after application of test potential or measure polarization index.

____ Insulation resistance measurements are always corrected to 40°C.

____ High potential dielectric tests determine maximum potential which insulation can withstand without failure. This test may be conducted as a proof test or as a controlled overvoltage test.

____ Starting and run current tests verify acceptable motor performance under load.

____ Vibration tests verify that rotating equipment are sufficiently rigid, aligned, and balanced to avoid excess vibration.

____ Generator loading tests verify the mechanical and electrical performance of generators under various load conditions.

____ Automatic features actuation tests of diesel generators verify diesel starting and generator loading whenever actuating conditions occur.

MATERIALS

The following materials are required to support this module:

1. megohmmeter
2. motors suitable for inspection.

PROCEDURES

The following activities reinforce the information presented in this module.

1. Measure insulation resistance of a motor:
   a. Select a motor from available resources such as portable fans, vacuum cleaners, etc.
   b. Obtain a megohmmeter from the instructor. A hand-cranked 250V/500V megger or a megohm bridge will suffice.
   c. Connect a shorting wire across each power lead and to the case of the motor for a four minute interval and then remove the shorting wire.
   d. Determine maximum test voltage from nameplate data (Note: If name plate data does not identify maximum rated voltage, use 250V for 115V motors and 500V for 220V motors.)
   e. Ensure megohmmeter output voltage is equal to or less than maximum test voltage. (Note: handpowered meggers typically have a selector switch or different output terminals for 250V and 500V selection.)
   f. Connect megohmmeter positive lead to one power conductor and negative lead to the case of the motor.

Ensure the lead connected to the case makes metal-to metal contact without interference from paint or other foreign matter.

g. Measure and record insulation resistance.

h. Sequentially connect megohmmeter positive lead to each additional power conductor and measure and record insulation resistance.

i. Determine acceptance of measurements using Formula 30-8-4.

2. Calculate insulation resistance and polarization index from the following readings of a high potential controlled overvoltage test performed at 40°C. Plot the readings and determine the step which indicates impending breakdown. Determine breakdown voltage. Use Data Table 30-8-1 for plotting and recording.

Test Voltage (kV)	Current (mA)	Time From Start(min)
20	200	1
20	80	10
21.8	81	11
23.6	82.5	12
25.4	84.5	13
27.2	87	14
29	90	15
30.8	93.5	16
32.6	97.5	17
34.4	102	18
36.2	107	19
38	112.5	20
39.5	119	21
41.6	130	22
43.4	165	23

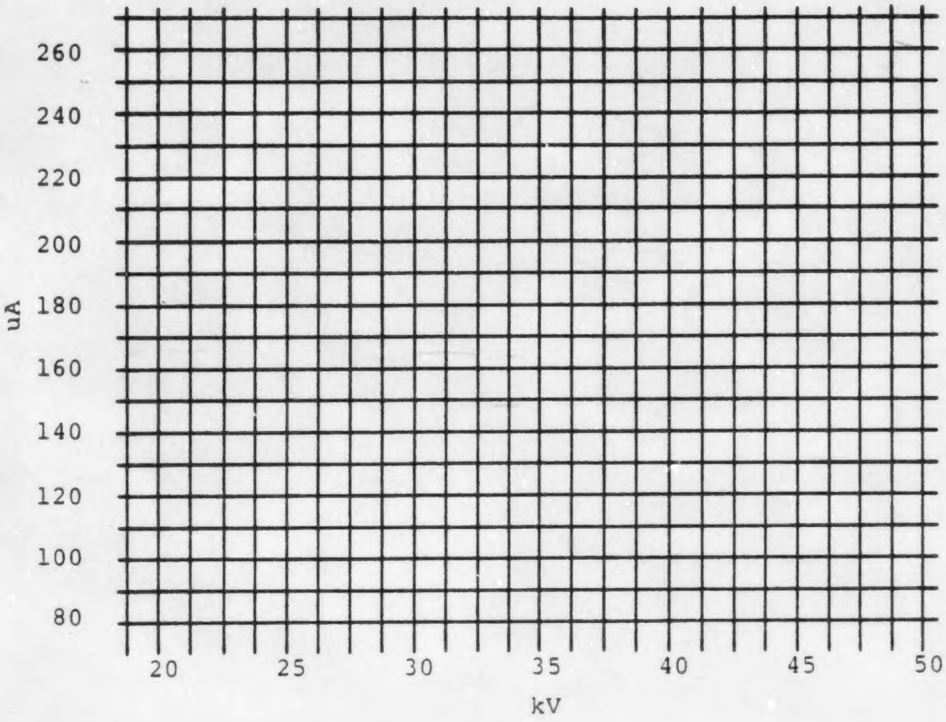
Data Table 30-8-1

Insulation Resistance at 1 minute: ______________

Insulation Resistance at 10 minutes: ____________

Polarization Index: ______________________________

Estimated Breakdown Voltage: _____________________



REFERENCE MATERIALS

IEEE, Guide for Operation and Maintenance of Turbine Generators, IEEE Standard #67, The Institute of Electrical and Electronic Engineers, 1972

IEEE, Recommended Practice for Testing Insulation Resistance of Rotating Machinery, IEEE Standard #43, The Institute of Electrical and Electronic Engineers, 1974

IEEE, Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage, IEEE Standard #95, The Institute of Electrical and Electronic Engineers, 1977

IEEE, Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations, IEEE Standard #387, The Institute of Electrical and Electronic Engineers, 1977

IEEE, Standard for Type Tests of Continuous Duty Class IE Motors for Nuclear Power Generating Stations, IEEE Standard #334, The Institute of Electrical and Electronic Engineers, 1974

NEMA, Motors and Generators, NEMA Publication MG1, National Electrical Manufacturers Association, 1978

Hubert, Charles I., Preventative Maintenance of Electrical Equipment, McGraw-Hill, 1969

ASME, Supplementary Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems for the Construction Phase of Nuclear Power Plants, The American Society of Mechanical Engineers, 1975

Mark's, Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw-Hill, 1978

Syska and Hennessy, Applied Preventative Maintenance, Engineering Management Division, Syska & Hennessy, Inc. 1976

TPC Training Systems, *Mechanical Maintenance*, Technical Publishing Company, 1974

TEST

1. State the purpose of preinstallation inspections.

2. Briefly describe typical preinstallation inspections of rotating equipment.

3. State the purpose of installation inspections.

4. Briefly describe typical installation inspections of rotating equipment.

5. State why shaft alignment is important.

6. Name and briefly describe two methods of inspecting shaft alignment.

7. Briefly describe the Langmuir theory of lubrication.

8. Define the following attributes of lubricating oils:
   a. viscosity

   b. flash point

   c. fire point

   d. auto-ignition point.

9. Name three basic types of oil lubricating systems and briefly describe each.
   a.

   b.

   c.

10. Differentiate between the attached force feed and the external force feed oil lubrication systems.

11. Name two types of grease lubrication systems and briefly describe each.
   a.

   b.

12. State the purpose of "turnover" tests of oil lubricating systems and name four items checked by these tests.

13. Name three items checked during load testing to verify satisfactory performance of oil lubricating systems.

14. State the purpose of each test:
    a. continuity

    b. insulation resistance

    c. high potential dielectric

    d. starting and run current

    e. vibration

    f. generator loading tests

    g. automatic features actuation of emergency diesel generators

15. Describe the effects on insulation resistance measurements by capacitance current, absorption current, and conduction current.

16. Describe the effects on insulation resistance of:
    a. surface condition
    b. moisture
    c. temperature
    d. magnitude of test potential
    e. duration of application of test potential
    f. residual charge

17. Describe an insulation resistance test using the polarization index method.

18. Describe a high potential dielectric test using the controlled overvoltage test.

19. Describe a starting and run current test for an electrical motor.

20. Describe a vibration test using a portable vibration detector.

21. Describe a generator loading test.

22. Describe a basic automatic features actuation test for an emergency diesel-generator.

NUCLEAR TECHNOLOGY

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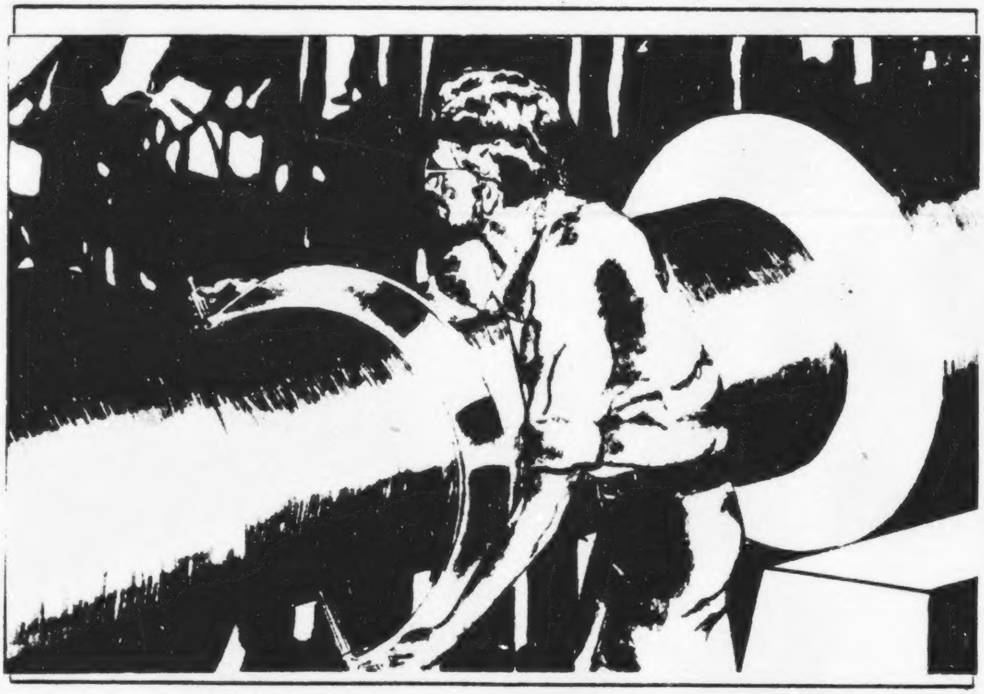
COURSE 30 - MECHANICAL INSPECTION



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NUCLEAR TECHNOLOGY SERIES

INDEX
for
COURSE 30, MECHANICAL INSPECTION (EIGHT MODULES)

NOTE: Each module in this Course is numbered separately, and the page numbers begin with page 1 in each module. Therefore, this Index lists for each entry the module number (underlined), followed by a comma and the page number. Figures and tables are listed by their numbers, followed by the module and page number in parentheses. A Master Index is available in a separate volume. This general index merges all index entries from the 35 Nuclear Courses. It is a valuable research tool, with which the student or researcher can locate all the references to any subject within the 35 Courses.

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